Network Working Group
Internet Draft
Intended Category: Informational

N. Leymann
C. Heidemann
Deutsche Telekom AG
M. Zhang
Huawei
M. Wasserman
Painless Security

Expires: January 7, 2016
July 6, 2015

GRE Tunnel Bonding
draft-zhang-gre-tunnel-bonding-00.txt

Abstract

It is an emerging demand to provide redundancy and load-sharing across wired and cellular links from a single service provider so that one customer is provided with "Hybrid Access" to the bonding of multiple heterogeneous connections.

In this document, GRE (Generic Routing Encapsulation) Tunnel Bonding is specified as an enabling approach for Hybrid Access. In GRE Tunnel Bonding, GRE tunnels per network connections are set up and bonded together to form a single GRE tunnel for a subscriber. Compared with each composing connection, the bonding connection promises increased access capacity and improved reliability.

Status of this Memo

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

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1. Introduction

Operators used to provide subscribers with separate access to their fixed broadband networks and mobile networks. It becomes desirable to bond the fixed and wireless networks together to offer customers with increased access capacity and improved reliability. Solutions that support Hybrid Access to fixed and wireless networks are required.

In this document, Hybrid Access focuses on the use case that DSL (Digital Subscriber Line) connection and LTE (Long Term Evolution) connection are bonded together to form a bonding connection. When the traffic volume exceeds the bandwidth of the DSL connection, the excess amount can be offloaded to the LTE connection. Hybrid Customer Premises Equipment (HCPE) is the equipment at the customer side

initiating the DSL and LTE connections. Hybrid Access Gateway (HAG) is the network function resides in the provider's networks to terminate the bonded connections. Note that if there are more than two connections need to be bonded, the GRE Tunnel Bonding mechanism can support as well. However, it's out the scope of this document.

This document bases the solution on GRE (Generic Routing Encapsulation) since GRE is widely supported in both fixed and mobile networks. GRE tunnels are set up per those heterogeneous connections (DSL+LTE) between HCPE and HAG. All these GRE tunnels are further bonded together to form a logical GRE tunnel for the customer. HCPE conceals the composing GRE tunnels from users and users simply treat the logical GRE tunnel as a single IP link. This provides an overlay: user IP packets (inner IP) is encapsulated with GRE which is in turn carried over IP (outer IP).

The design of the GRE Tunnel Bonding exhibits how the function blocks of Hybrid Access are realized, such as traffic classification, distribution, recombination, measurement of the connection, etc. Although the industry might develop more solutions for Hybrid Access besides GRE Tunnel Bonding, the function blocks need to be realized are common and the mapping out of the function blocks here is referential to other potential solutions.

2. Acronyms and Terminology

GRE: Generic Routing Encapsulation

DSL: Digital Subscriber Line

LTE: Long Term Evolution

Hybrid Access: The bonding of multiple access connections based on heterogeneous technologies (e.g., DSL and LTE).

HCPE: Hybrid Customer Premises Equipment (CPE). A CPE enhanced to support the simultaneous use of both fixed broadband and 3GPP access connections.

HAG: Hybrid Access Gateway. A logical function in the operator network implementing a bonding mechanism for customer access services.

C: The endpoint of the bonding connection at the HCPE.

E: The endpoint of the LTE connection resides in HCPE.

D: The endpoint of the DSL connection resides in HCPE

H: The endpoint of the bonding connection at HAG. Usually, this is also used as the endpoint for each heterogeneous connection.

CIR: Committed Information Rate [RFC2698]

RTT: Round Trip Time

FQDN: A Fully Qualified Domain Name (FQDN) is a domain name that includes all higher level domains relevant to the entity named. [RFC1594]

DSCP: The six-bit codepoint (DSCP) of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers [RFC2724].

BRAS: Broadband Remote Access Server

PGW: Packet Data Network Gateway. In the Long Term Evolution (LTE) architecture for the Evolved Packet Core (EPC), the PGW acts as an anchor for user plane mobility.

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 RFC 2119 [RFC2119].

3. Use Case

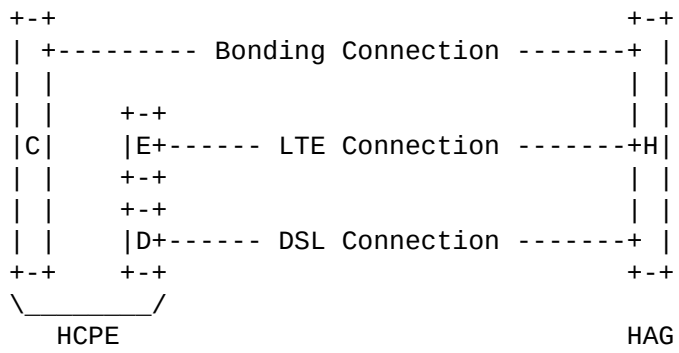


Figure 3.1: Offloading from DSL to LTE, increased access capacity

For a Service Provider who owns heterogeneous networks, such as fixed and mobile, customers wish to use its networks simultaneously with increased access capacity rather than just uses a single network. As shown by the reference model in Figure 3.1, the customer expects the whole bandwidth of the bonding connection equals the sum of the bandwidth of the DSL connection and the LTE connection between HCPE

and HAG. In other words, when the traffic volume exceeds the bandwidth of the DSL connection, the excess amount may be offloaded to the LTE connection.

Most common implementation balance the load among multiple paths. However, the use case described here is about per-packet offloading rather than per-flow load-balance. For the per-flow load-balance, the maximum bandwidth that may be used by a flow actually equals to the bandwidth of the connection selected. The GRE Tunnel Bonding mechanism is able to support the use case that requires per-flow traffic classification and distribution though it's out the scope of this document.

Use cases with more than two connections between HCPE and HAG is out the scope of this document. However, the GRE Tunnel Bonding mechanism can well support those use cases.

4. Overview

In this document, the widely supported GRE is chosen as the tunneling technique. With the newly defined control protocol, GRE tunnels are setup on top of the DSL and LTE connections which are ended at D and H or E and H. These tunnels are bonded together to form a single logical bonding GRE tunnel whose endpoint IP addresses are C and H. Customers uses this logical tunnel without knowing the composing GRE tunnels.

4.1. Control Plane

A clean-slate control protocol is designed to manage the GRE tunnels that are setup per heterogeneous connections between HCPE and HAG. The goal is to design a compact control plane for Hybrid Access only instead of reusing existing control planes.

In order to measure the performance of connections, control packets need co-route the same path with data packets. Therefore, a GRE Channel is opened for the purpose of data plane forwarding of control plane packets. The GRE header as specified in [RFC2890] is being used. The GRE Protocol Type (tbd1) is used to identify this GRE Channel. A family of control messages are encapsulated with GRE header and carried over this channel. Attributes, formatted in Type-Length-Value style, are further defined and included in each control message.

With the newly defined control plane, the GRE tunnels between HCPE and HAG can be established, managed and released without the involvement of man-power of operators.

4.2. Data Plane

With the new defined control plane, GRE tunnels can be automatically setup per heterogeneous connections between HCPE and HAG. For the use case depict in Section 3, there are the GRE tunnel ended at the DSL WAN interfaces (shorted as DSL GRE tunnel) and the GRE tunnel ended at the LTE WAN interfaces (shorted as LTE GRE tunnel). Each tunnel may carry user's IP packets as payload, which forms a typical IP-in-IP overlay. These tunnels are bonded together to offer a single access point to customers.

The GRE header per [RFC2890] is used to encapsulate data packets. The Protocol Type is 0x0800, which indicates the inner header is an IP header. For per-packet offloading use case, the Key field is used as a clear-text password. The Sequence Number field is used to maintain the sequence of packets transported in all GRE tunnels as a single flow between a pair of HCPE and HAG.

For the per-flow traffic classification and distribution, the Key field will be used as the demultiplexer for flows. The Acknowledgement field as specified in [RFC2637] will be used to achieve a low-level congestion and flow control.

4.3. Traffic Classification and Distribution

For the offloading use case, the coloring mechanism specified in [RFC2698] is being used to classify customer's IP packets, both upstream and downstream, into the DSL GRE tunnel or LTE GRE tunnel. Packets colored as green will be distributed into the DSL GRE tunnel and packets colored as yellow will be distributed into the LTE GRE tunnel. For the scenario that requires more than two GRE tunnels, multiple levels of token buckets might be realized. For example, the packets classified as not to be distributed to DSL may be further colored as either to be distributed to LTE or distributed to WiFi. The implementation detail is out the scope of this document.

The Committed Information Rate (CIR) of the coloring mechanism is set to the total DSL WAN bandwidth minus the bypassing DSL bandwidth (See Section 4.4.). The total DSL WAN bandwidth MAY be configured, MAY be got from the SOAP server and MAY be timely detected and reported by using ANCP [RFC6320].

Besides the per-packet offloading use case, the GRE Tunnel Bonding mechanism is also applicable to per-flow classification and distribution.

4.4. Traffic Recombination

The recombination function at the receiver provides the in-order delivery of customers' traffic. As specified in [RFC2890], the receiver maintains a small amount of reordering buffer and order the data packets in this buffer by the Sequence Number field of the GRE header. For the offloading use case, all bonded GRE tunnels use the same Key value. All packets carried on these bonded GRE tunnels go into a single reordering buffer.

For the per-flow classification and distribution, Sequence Numbers are set per Key values at the sender. Buffers per Key values are maintained at the receiver. In addition, the Acknowledge Number field can be introduced in order to achieve a low level congestion and flow control [RFC2637]. As stated in [RFC2637], retransmissions are not performed by the tunnel peers.

4.5. Bypassing

Service Providers need some types of services not delivered by the bonding of GRE tunnels. For example, Service Providers do not expect the real-time IPTV to be carried by the LTE GRE tunnel. It's required that these kind of services bypass the GRE Tunnel Bonding and use just the raw DSL bandwidth. In this way, the do not subject to the traffic classification and distribution specified as above. There are two kinds of bypassing:

- Fully bypassing: The raw DSL connection used for bypassing is not controlled by HAG. It may or may not go through HAG.

- Partial bypassing: HAG controls the raw DSL connection used for bypassing. The raw DSL connection goes through HAG

For either of the bypassing, HAG notifies the the service types that need to bypass the bonded GRE tunnels using the Filter List Package attribute as specified in Section 5.6.2. HCPE and HAG need set aside the DSL bandwidth for bypassing. The available DSL bandwidth for the GRE Tunnel Bonding equals to the total DSL bandwidth minus the bypassing bandwidth.

4.6. Measurement

Since control packets co-route the same path with data packets. The real performance of the data paths (e.g., the GRE tunnels) can be measured. The GRE Tunnel Hello messages specified in Section 5.3 are used to carry the timestamp information and the Round Trip Time (RTT) value can therefore be calculated based on the timestamp.

Besides the end to end delay of the GRE tunnels, HCPE and HAG need also measure the capacity of the tunnels. For example, for the fully

bypassing, HCPE is REQUIRED to timely measure the downstream bypassing bandwidth and report it to HAG (See Section 5.6.1.).

4.7. Policy Control Considerations

Operators and customers may input policies into the GRE Tunnel Bonding. These policies will be interpreted into parameters or actions that impact the traffic classification, distribution, combination, measurement and bypassing.

Operators and customers may offer the service types that need to bypass the bonded GRE tunnels. These service types will be delivered from HAG to HCPE and HCPE will stick to raw DSL interfaces to transmit traffic of these service types.

Since the GRE tunnels are setup on top of heterogeneous DSL and LTE connections, if the difference of the transmission delays of these connections exceeds a given threshold for a certain period, HCPE and HAG should be able to stop the offloading behavior and fallback to a traditional transmission mode, where the LTE GRE tunnel is disabled while all traffic is transmitted over the DSL GRE tunnel. Operators are allowed to defined this threshold and period.

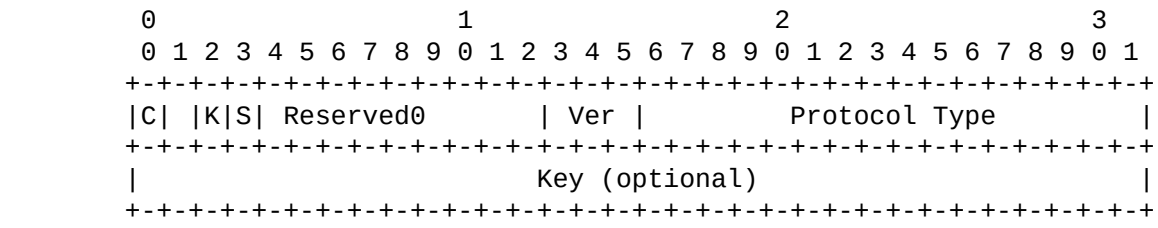
Operators may determine the maximum allowed size (See MAX_PERFLOW_BUFFER in [RFC2890]) of the buffer for reordering. They may also define the maximum time (See OUTOFORDER_TIMER in [RFC2890]) that a packet can stay in the buffer for reordering. These parameters impact the traffic recombination.

Operators may specify the interval for sending Hello messages and the retry times for HCPE or HAG to send out Hello messages before it declare the failure of a connection.

5. Control Protocol Specification (Control Plane)

Control messages are used to establish, maintain, measure and tear down GRE tunnels between the HCPE and HAG. Also, the control plane undertakes the responsibility to bond tunnels and convey traffic policies.

For the purpose of measurement, control messages need to be delivered as GRE encapsulated packets and delivered as co-route with data plane packets. The new GRE Protocol Type [tbd1] is allocated for this purpose and the standard GRE header as per [RFC2890] is used. The format of the GRE header is as follows:



C (Bit 0)
Checksum Present. Set to zero (0).

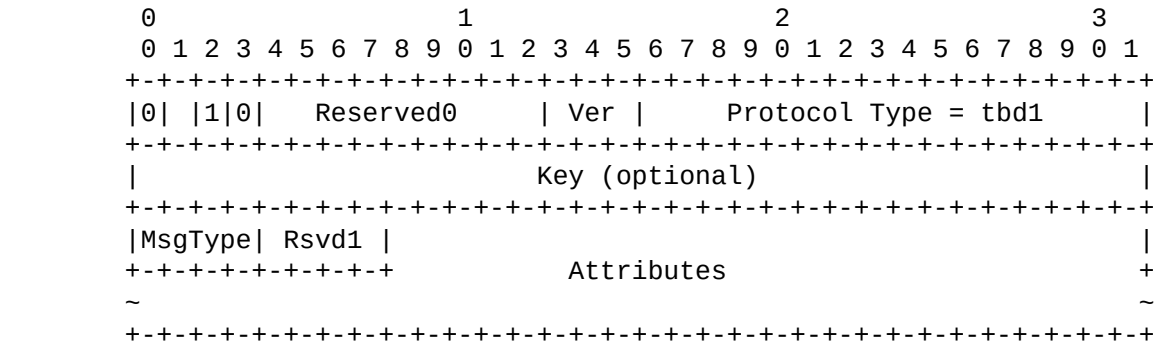
K (Bit 2)
Key Present. Set to one (1).

S (Bit 3)
Sequence Number Present. Set to zero (0).

Protocol Type (2 octets)
Set to [tbd1].

Key
The Key field is used as a security feature, functioning as a 32-bit clear-text password. Also, the Key field is used as a demultiplexer for GRE tunnels at the HAG. This value of the Key is generated by HAG and informed to HCPE. (See Section 5.2.9.)

The general format of the entire control message is as follows:

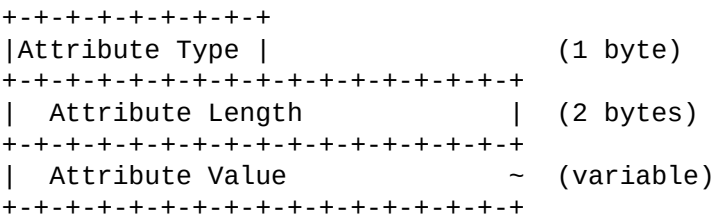


MsgType (4 bits)
Message Type. The control message family contains the following 6 types of control messages:

Control Message Family	Type
GRE Tunnel Setup Request	1
GRE Tunnel Setup Accept	2
GRE Tunnel Setup Deny	3
GRE Tunnel Hello	4
GRE Tunnel Tear Down	5
GRE Tunnel Notify	6
Reserved	0,7-15

Rsvd1 (4 bits)
Reserved1. These bits MUST be set to zero.

Attributes
The Attributes field includes the attributes that need to be carried in the control message. Each Attribute has the following format.



Attribute Type (1 octet)
The Attribute Type specifies the type of the attribute.

Attribute Length (2 octets)
Attribute Length indicates the length of the Attribute Value.

Attribute Value (variable)
The Attribute Value includes the value of the attribute.

All control messages are sent in network order (high order octets first). Since the Protocol Type carried in the GRE header for the control message is tbd1, the receiver will determine to consume it locally rather than further forwarding.

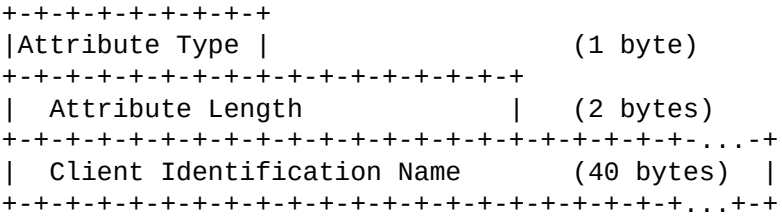
5.1. GRE Tunnel Setup Request

HCPE uses the GRE Tunnel Setup Request message to request HAG to establish GRE tunnels. It is sent out from HCPE's LTE and DSL WAN interfaces separately. Attributes that need be to included in this message are defined in Section 5.1.1 through Section 5.1.3.

5.1.1. Client Identification Name

Operator uses the Client Identification Name (CIN) to identify the HCPE. The HCPE sends the CIN to HAG for authentication and authorization as specified in [TS23.401]. It's REUIRED that the GRE Tunnel Setup Request message sent out from the LTE WAN interface contains the CIN attribute while the GRE Tunnel Setup Request message sent out from the DSL WAN interface does not contain this attribute.

The CIN attribute has the following format:



Attribute Type
CIN, set to 3.

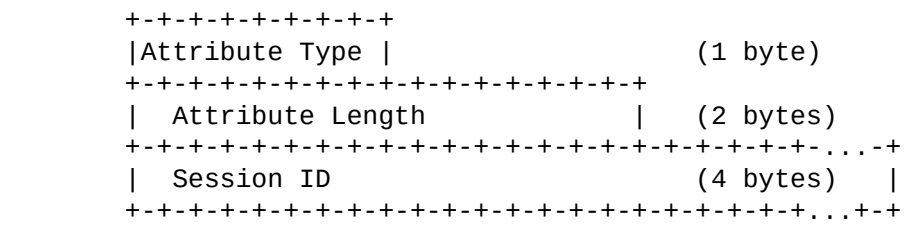
Attribute Length
Set to 40.

Client Identification Name
This is a 40 bytes ANSI string value set by the operator. It's used as the identification of HCPE in the operator's network.

5.1.2. Session ID

This Session ID is generated by HAG when the LTE GRE Tunnel Setup Request message is received and then notifies the Session ID to HCPE through the LTE GRE Tunnel Setup Accept message. For those WAN interfaces that need to be bonded together, the HCPE MUST use the same Session ID. The HCPE MUST carry the Session ID attribute in each DSL GRE Tunnel Setup Request message. For the first time that the LTE GRE Tunnel Setup Request message is sent to the HAG, the Session ID attribute need not be included. However, if the LTE GRE Tunnel fails and HCPE tries to revive it, the LTE GRE Tunnel Setup Request message MUST include the Session ID attribute.

The Session ID attribute has the following format:



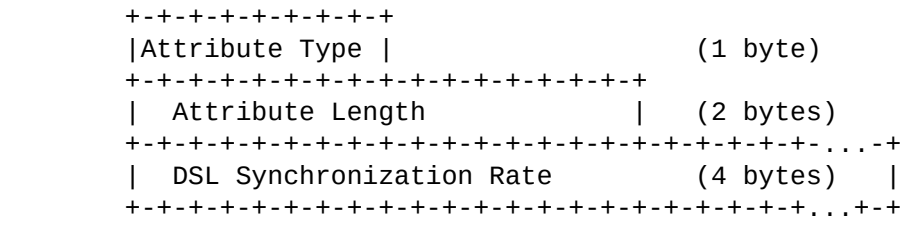
Attribute Type
Session ID, set to 4.

Attribute Length
Set to 4.

Session ID
This is a 4 bytes ANSI string value generated by the HAG. It's used as the identification of bonded GRE Tunnels.

5.1.3. DSL Synchronization Rate

HCPE uses the DSL Synchronization Rate to notify HAG about the downstream bandwidth of the DSL link. The DSL GRE Tunnel Setup Request message MUST include the DSL Synchronization Rate attribute. The LTE GRE Tunnel Setup Request message SHOULD NOT include this attribute.



Attribute Type
DSL Synchronization Rate, set to 7.

Attribute Length
Set to 4.

DSL Synchronization Rate
This is a unsigned integer with the unit of kbps.

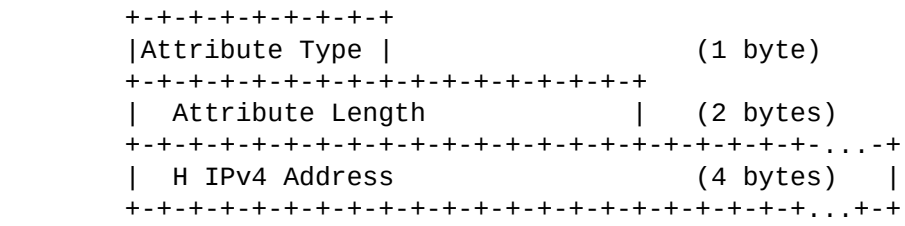
5.2. GRE Tunnel Setup Accept

HAG uses the GRE Tunnel Setup Accept message as the response to the GRE Tunnel Setup Request message. This message indicates the permission of the tunnel establishment and carries parameters of the

GRE tunnels. Attributes that need be to included in this message are defined in Section 5.2.1 through Section 5.2.13.

5.2.1. H IPv4 Address

HAG uses the H IPv4 Address attribute to inform HCPE the H IPv4 address. HCPE uses the H IPv4 address as the endpoint IPv4 address of the GRE tunnels. The LTE GRE Tunnel Setup Accept message MUST include the H IPv4 Address attribute.



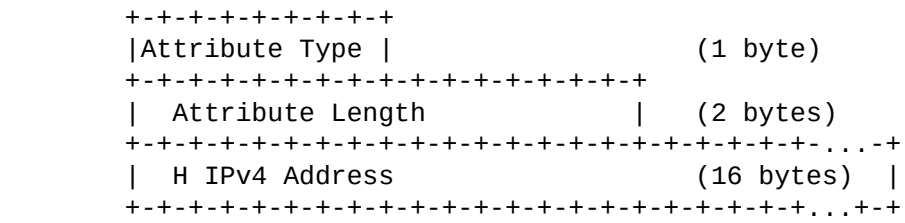
Attribute Type
H IPv4 Address, set to 1.

Attribute Length
Set to 4.

H IPv4 Address
Set to the pre-configured IPv4 address which is used as the endpoint IP address of GRE tunnels by HAG.

5.2.1. H IPv6 Address

HAG uses the H IPv6 Address attribute to inform HCPE the H IPv6 address. HCPE uses the H IPv6 address as the endpoint IPv6 address of the GRE tunnels. The LTE GRE Tunnel Setup Accept message MUST include the H IPv6 Address attribute.



Attribute Type
H IPv6 Address, set to 1.

Attribute Length
Set to 16.

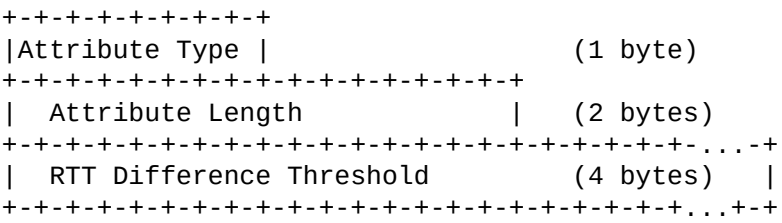
H IPv6 Address
Set to the pre-configured IPv6 address which is used as the endpoint IP address of GRE tunnels by HAG.

5.2.3. Session ID

The LTE GRE Tunnel Setup Accept message MUST include Session ID attribute as defined in Section 5.1.2.

5.2.4. RTT Difference Threshold

HAG uses the RTT Difference Threshold to attribute to inform HCPE the acceptable threshold of RTT difference between the DSL link and the LTE link. If the measured RTT difference exceeds this threshold SHOULD stop offloading traffic to the LTE GRE tunnel. The LTE GRE Tunnel Setup Accept message MUST include the RTT Difference Threshold attribute.



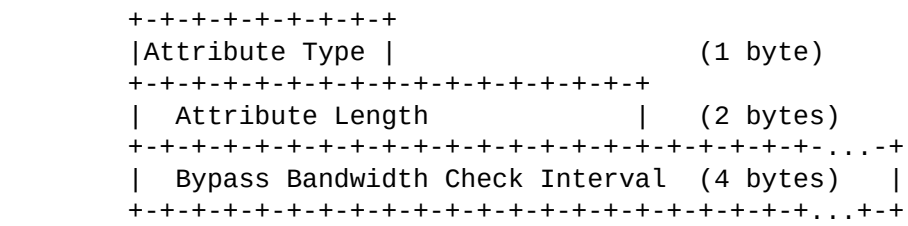
Attribute Type
RTT Difference Threshold, set to 9.

Attribute Length
Set to 4.

RTT Difference Threshold
A unsigned integer with the unit of millisecond. This value can be chosen in the range 0 through 1000.

5.2.5. Bypass Bandwidth Check Interval

HAG uses the Bypass Bandwidth Check Interval attribute to inform HCPE the interval that the bypass bandwidth should be checked. HCPE should check the bypass bandwidth of the DSL WAN interface in each time period as indicates by this interval. The LTE GRE Tunnel Setup Accept message MUST include the Bypass Bandwidth Check Interval attribute.



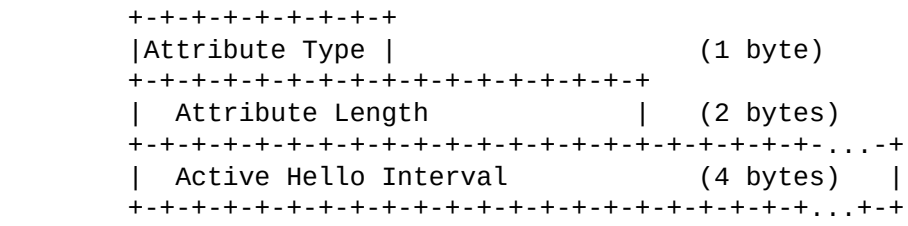
Attribute Type
Bypass Bandwidth Check Interval, set to 10.

Attribute Length
Set to 4.

Bypass Bandwidth Check Interval
A unsigned integer with the unit of second. This value can be chosen in the range 0 through 300.

5.2.6. Active Hello Interval

HAG uses the Active Hello Interval attribute to inform HCPE the pre-configured interval for sending out GRE Tunnel Hellos. HCPE should send out GRE Tunnel Hellos via both the DSL and LTE WAN interfaces in each time period as indicates by this interval. The LTE GRE Tunnel Setup Accept message MUST include the Active Hello Interval attribute.



Attribute Type
Active Hello Interval, set to 14.

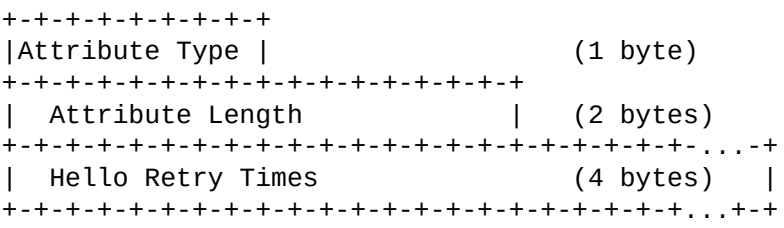
Attribute Length
Set to 4.

Active Hello Interval
A unsigned integer with the unit of second. This value can be chosen in the range 0 through 100.

5.2.7. Hello Retry Times

HAG uses the Hello Retry Times attribute to inform HCPE the retry

times for sending GRE Tunnel Hellos. If the HCPE does not receive any acknowledgement to the GRE Tunnel Hellos from the HAG over a GRE Tunnel after it tries the times specified in this attribute, the HCPE will declare the failure this GRE Tunnel. The LTE GRE Tunnel Setup Accept message MUST include the Hello Retry Times attribute.



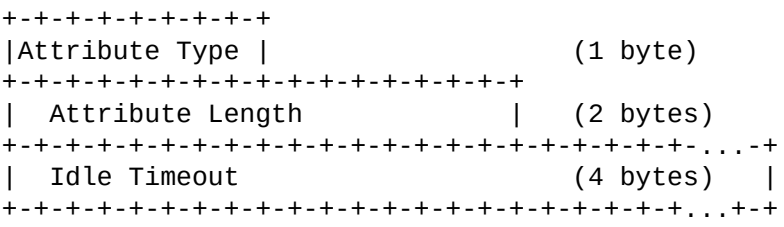
Attribute Type
Hello Retry Times, set to 15.

Attribute Length
Set to 4.

Hello Retry Times
A unsigned integer number which takes value in the range 3 through 10.

5.2.8. Idle Timeout

HAG uses the Idle Timeout attribute to inform HCPE the pre-configured timeout value to terminate the DSL GRE tunnel. When an LTE GRE Tunnel failure is detected, all traffic will be sent over the DSL GRE tunnel. If the failure of the LTE GRE tunnel lasts longer than the Idle Timeout, the traffic will be sent over the raw DSL rather the tunnel over it, and the DSL GRE tunnel SHOULD be terminated. The LTE Tunnel Setup Accept message MUST include the Idle Timeout attribute.



Attribute Type
Idle Timeout, set to 16.

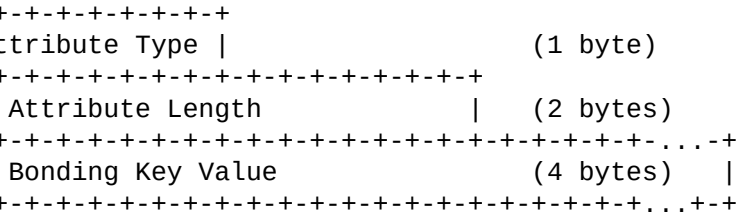
Attribute Length
Set to 4.

Idle Timeout
A unsigned integer number with the unit of second. It takes value in the range 0 through 172,800 with the granularity of 60. The default value is 1,440 (24 hours). The value 0 indicates the idle timer never expires.

5.2.9. Bonding Key Value

HAG uses the Bonding Key Value attribute to inform HCPE the number which is to be used as the Key of the GRE header for each tunneled control messages. The Bonding Key Value is generated by HAG and used for the purpose of demultiplexing. HAG is REQUIRED to distinguish the GRE tunnels from the Bonding Key Value. Different tunnels MUST use different Bonding Key Values. HAG SHOULD identify the GRE tunnels by their source IP addresses which are carried in the outer IP header. Since the CIN attribute is carried in the GRE Tunnel Setup Request sent on the LTE GRE tunnel only, HAG can figure out the source IP address used for the LTE GRE tunnel from the message carrying the CIN attribute. Similarly, HAG can figure out the source IP address used for the DSL GRE tunnel from the message carrying the DSL Synchronization Rate attribute.

The specific method used to generate this number is up to implementations. The Pseudo Random Number Generator defined in ANSI X9.31 Appendix A.2.4 is RECOMMENDED. Both the LTE GRE Tunnel Setup Accept message and the DSL GRE Tunnel Setup Accept message MUST include the Bonding Key Value attribute.



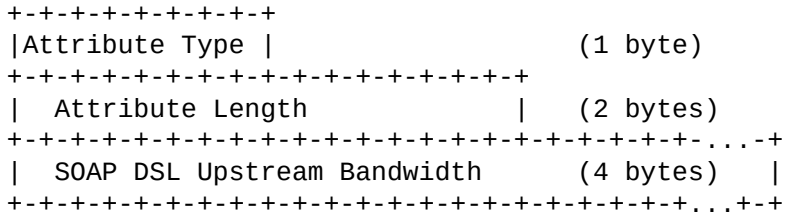
Attribute Type
Bonding Key Value, set to 20.

Attribute Length
Set to 4.

Bonding Key Value
A 32-bit number generated by the HAG. It’s REQUIRED that different tunnels are allocated with different Key values. The HAG MAY set aside a few bits (e.g., the highest 4 bits) in the Key field as the demultiplexer for the tunnels while other bits are filled in with a value generated by a random number generator.

5.2.10. SOAP DSL Upstream Bandwidth

HAG obtains the upstream bandwidth of the DSL link from the SOAP server and uses the SOAP DSL Upstream Bandwidth attribute to inform HCPE. The HCPE uses this informed upstream bandwidth as the Committed Information Rate for the DSL link [RFC2698]. The DSL GRE Tunnel Setup Accept message MUST include the SOAP DSL Upstream Bandwidth attribute.



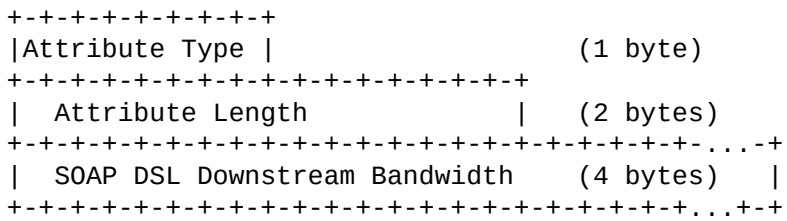
Attribute Type
SOAP DSL Upstream Bandwidth, set to 22.

Attribute Length
Set to 4.

SOAP DSL Upstream Bandwidth
A unsigned integer with the unit of kbps.

5.2.11. SOAP DSL Downstream Bandwidth

HAG obtains the downstream bandwidth of the DSL link from the SOAP server and uses the SOAP DSL Downstream Bandwidth attribute to inform HCPE. The HCPE uses this informed downstream bandwidth as the base in calculating of the bypassing bandwidth. The DSL GRE Tunnel Setup Accept message MUST include the SOAP DSL Downstream Bandwidth attribute.



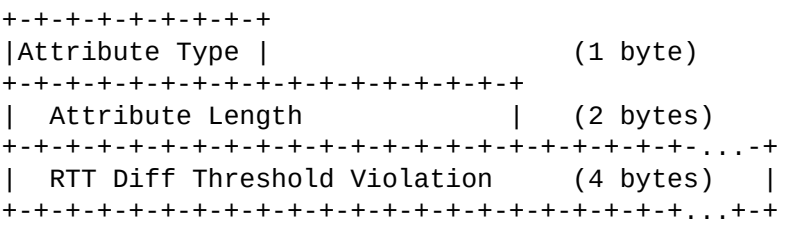
Attribute Type
SOAP DSL Downstream Bandwidth, set to 23.

Attribute Length
Set to 4.

SOAP DSL Downstream Bandwidth
A unsigned integer with the unit of kbps.

5.2.12. RTT Difference Threshold Violation

HAG uses the RTT Difference Threshold Violation attribute to inform HCPE the times of the measurements that the RTT Difference Threshold (See Section 5.2.4.) is continuously detected to be violated. If RTT Difference Threshold is continuously detected to be violated more than this informed times, the HCPE MUST stop using the LTE GRE tunnel. The LTE GRE Tunnel Setup Accept message MUST include the RTT Difference Threshold Violation attribute.



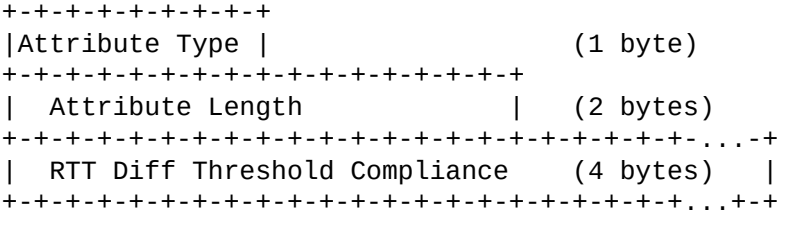
Attribute Type
RTT Difference Threshold Violation, set to 24.

Attribute Length
Set to 4.

RTT Difference Threshold Violation
A unsigned integer which takes from the range 1 through 25.

5.2.13. RTT Difference Threshold Compliance

HAG uses the RTT Difference Threshold Compliance attribute to inform HCPE the times of the measurements that the RTT Difference Threshold (See Section 5.2.4.) is continuously detected to be compliant. If the RTT Difference Threshold is continuously detected to be compliant more than this informed times, the HCPE MAY resume the LTE GRE tunnel. The LTE GRE Tunnel Setup Accept message MUST include the RTT Difference Threshold Compliance attribute.



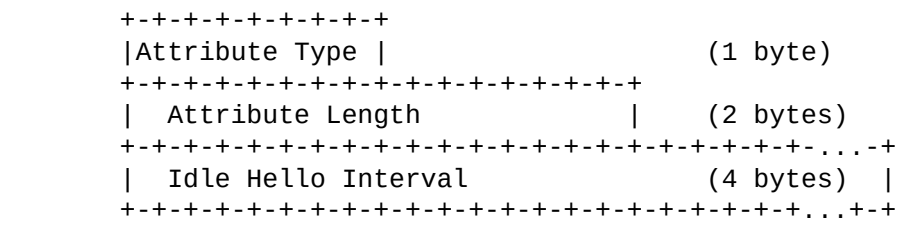
Attribute Type
RTT Diff Threshold Compliance, set to 25.

Attribute Length
Set to 4.

RTT Diff Threshold Compliance
A unsigned integer which takes from the range 1 through 25.

5.2.14. Idle Hello Interval

HAG uses the Idle Hello Interval attribute to inform HCPE the pre-configured interval for sending out GRE Tunnel Hellos when the customer is detected to be idle. HCPE SHOULD begin to send out GRE Tunnel Hellos via both the DSL and LTE WAN interfaces in each time period as indicates by this interval, if the bonding tunnels have seen no traffic longer than the "No Traffic Monitored Interval" (See Section 5.2.15.). The LTE GRE Tunnel Setup Accept message MUST include the Idle Hello Interval attribute.



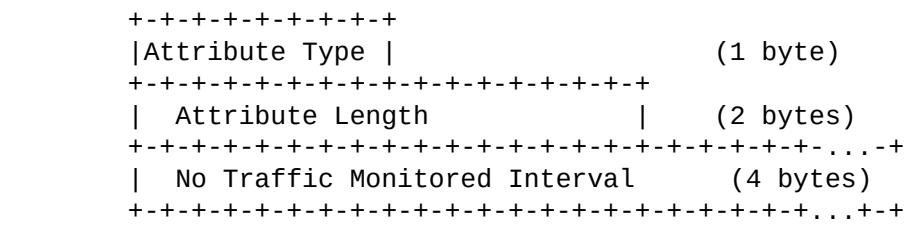
Attribute Type
Idle Hello Interval, set to 31.

Attribute Length
Set to 4.

Idle Hello Interval
A unsigned integer with the unit of second. This value can be chosen in the range 100 through 86,400 (24 hours) with the granularity of 100. The default value is 1800 (30 minutes).

5.2.15. No Traffic Monitored Interval

HAG uses the No Traffic Monitored Interval attribute to inform HCPE the pre-configured interval for switching the GRE Tunnel Hello mode. If traffic is detected on the bonding GRE tunnels before this informed interval expires, the HCPE SHOULD switch to Active Hello Interval. The LTE GRE Tunnel Setup Accept message MUST include the No Traffic Monitored Interval attribute.



Attribute Type
   No Traffic Monitored Interval, set to 32.

Attribute Length
   Set to 4.

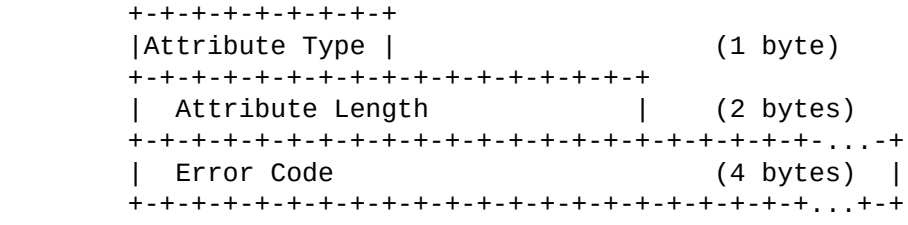
No Traffic Monitored Interval
   A unsigned integer with the unit of second. This value can be chosen in the range 30 through 86,400 (24 hours). The default value is 60.

5.3. GRE Tunnel Setup Deny

HAG MUST sends the GRE Tunnel Setup Deny message to HCPE if the GRE tunnel setup request from this HCPE is denied. The HCPE MUST terminate the GRE tunnel setup process as soon as it receives the GRE Tunnel Setup Deny message.

5.3.1. Error Code

HAG uses the Error Code attribute to inform HCPE the error code. The error code depicts the reason why the GRE tunnel setup request is denied. Both the LTE GRE Tunnel Setup Deny message and the DSL GRE Tunnel Setup Deny message MUST include the Error Code attribute.



Attribute Type
   Error Code, set to 17.

Attribute Length
   Set to 4.

Error Code

A unsigned integer. The list of the codes are listed as follows.

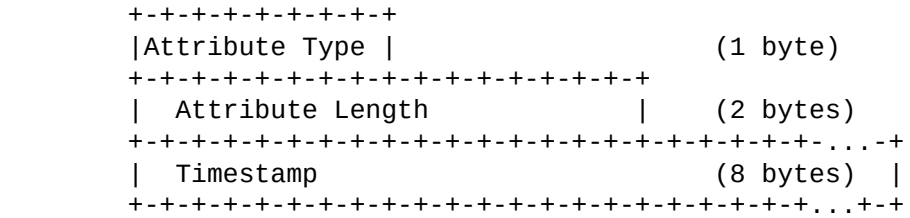
1: HAG is not reachable via LTE during GRE tunnel setup request.
2: HAG is not reachable via DSL during GRE tunnel setup request.
3: LTE GRE tunnel to the HAG fails.
4: DSL GRE tunnel to the HAG fails.
5: The given DSL User ID is not allowed to use GRE tunnel bonding service.
6: The given User Alias (TOID)/User ID (GUID) is not allowed to use GRE tunnel bonding service.
7: LTE and DSL User IDs mismatching.
8: HAG denies the GRE tunnel setup request since a bonding session with the same User ID already exists.
9: HAG denies the GRE tunnel setup request since the user's CIN is not permitted.
10: HAG terminates a GRE tunnel bonding session for maintenance reasons.
11: There is a communication error between the HAG and SOAP server during the LTE tunnel setup request.
12: There is a communication error between the HAG and SOAP server during the DSL tunnel setup request.

5.4. GRE Tunnel Hello

After the GRE tunnel is established, the HCPE begins to periodically send out GRE Tunnel Hello messages while the HAG acknowledges by returning the GRE Tunnel Hello messages back to HCPE, until the tunnel is terminated.

5.4.1. Timestamp

HAG uses the Timestamp attribute to inform HCPE the timestamp value that is used for RTT calculation. Both the LTE GRE Tunnel Hello message and DSL GRE Tunnel Hello message MUST include the Timestamp attribute.



Attribute Type
Timestamp, set to 5.

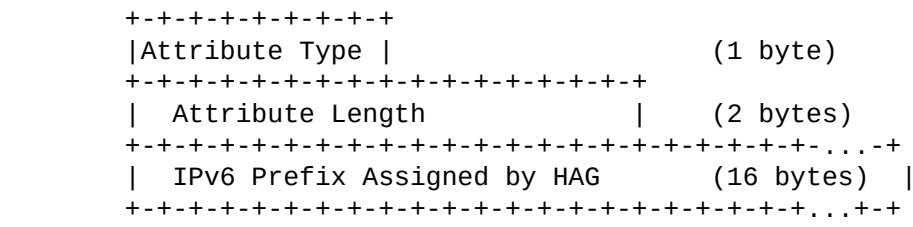
Attribute Length

Set to 8.

Timestamp
The high-order 4 octets indicate a unsigned integer with the unit of second; the low-order 4 octets indicate a unsigned integer with the unit of millisecond.

5.4.2. IPv6 Prefix Assigned by HAG

HAG uses the IPv6 Prefix Assigned by HAG attribute to inform HCPE the assigned IPv6 prefix. This IPv6 prefix is to be captured by the Lawful Interception. Both the LTE GRE Tunnel Hello message and the DSL GRE Tunnel Hello message MUST include the IPv6 Prefix Assigned by HAG attribute.



Attribute Type
IPv6 Prefix Assigned by HAG, set to 13.

Attribute Length
Set to 17.

IPv6 Prefix Assigned by HAG
The highest-order 16 octets encode an IPv6 address. The lowest-order one octet encodes the length of a network mask. These two values are put together to represent an IPv6 prefix.

5.5. GRE Tunnel Tear Down

HAG can terminate a GRE tunnel by sending the GRE Tunnel Tear Down message to the HCPE. The Error Code attribute as defined in Section 5.3.1 MUST be included in this message.

5.6. GRE Tunnel Notify

HCPE and HAG uses the GRE Tunnel Notify message to notify each other about their status, the information for the bonding tunnels, the actions need to be taken, etc.

Usually, the receiver just sends the received attributes back as the acknowledgement for each GRE Tunnel Notify message. There is an

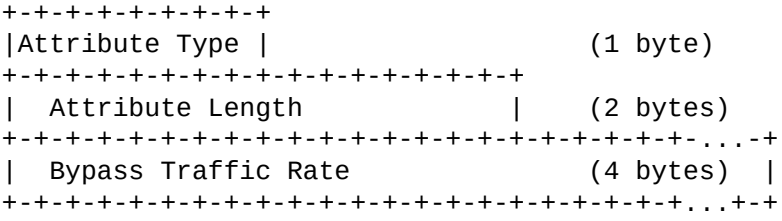
exception for the Filter List Package. Since the size of the Filter List Package attribute can be very large, a special attribute is specified in Section 5.6.12 as the acknowledgement.

Attributes that need be to included in the GRE Tunnel Notify message are defined in Section 5.6.1 through Section 5.6.15.

5.6.1. Bypass Traffic Rate

There are a few types of traffic that need to transmitted over the raw DSL WAN interface rather than the bonding GRE tunnels. The HCPE has to set aside a bypass bandwidth on the DSL WAN interface for these kind of traffic types. Therefore, the available bandwidth of the DSL GRE tunnel is the entire DSL WAN interface bandwidth minus the occupied bypass bandwidth.

HCPE uses the Bypass Traffic Rate attribute to inform HAG the downstream bypass bandwidth for the DSL WAN interface. The Bypass Traffic Rate attribute will be included in the DSL GRE Tunnel Notify message. HAG calculates the available downstream bandwidth for the DSL GRE tunnel as the SOAP DSL Downstream Bandwidth minus this informed bypass bandwidth. This available DSL bandwidth will be used as the Committed Information Rate (CIR) of the coloring system [RFC2698].



Attribute Type
Bypass Traffic Rate, set to 6.

Attribute Length
Set to 4.

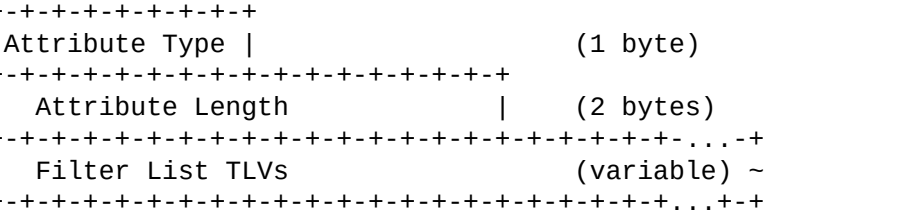
Bypass Traffic Rate
A unsigned integer with the unit of kbps.

5.6.2. Filter List Package

HAG uses the Filter List Package attribute to inform HCPE the service types that need to bypass the bonding GRE tunnels. Each Filter List Package carries a collection of Filter List TLVs and each such Filter List TLV specifies a filter item. At the HCPE, a list of filter items

is maintained. Also, HCPE need maintain an exception list of filter items. For example, the packets carrying the control messages defined in this document should be excluded from the filter list.

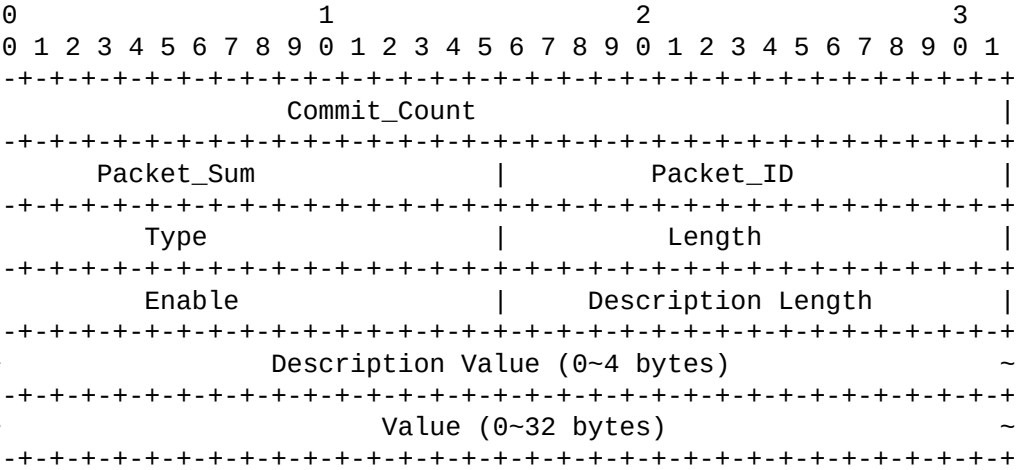
Incoming packets that match an filter item in the filter list while not match any item in the exception list MUST be transmitted over the raw DSL rather than the bonding GRE tunnels. Both the LTE GRE Tunnel Notify message and GRE Tunnel Notify message MAY include the Filter List Package attribute. The DSL GRE Tunnel Notify message is preferred.



Attribute Type
Filter List Package, set to 8.

Attribute Length
The total length of the Filter List TLVs. The maximum length is 969 bytes.

Filter List TLVs
Each Filter List TLV has the following format.



Commit_Count
A unsigned integer which identifies the version of the Filter List Package. HCPE will refresh its filter list, when a new

Commit_Count is received.

Packet_Sum
If the Filter List Package attribute might make the control message larger than the MTU, fragmentation is used. The Packet_Sum indicates the total number of Filter List Packages.

Packet_ID
The fragmentation index of one of those multiple Filter List Packages.

Type
The Type of the Filter List TLV. Currently used types are described as follows.

Filter List TLVs	Type
FQDN [RFC1594]	1
DSCP [RFC2724]	2
Destination Port	3
Destination IP	4
Destination IP&Port	5
Source Port	6
Source IP	7
Source IP&Port	8
Source Mac	9
Protocol	10
Source IP Range	11
Destination IP Range	12
Source IP Range&Port	13
Destination IP Range&Port	14
Reserved	

Length
The length of the Filter List TLV. Commit_Count, Packet Sum, Packet ID, Type and Length are excluded.

Enable
Whether the filter item defined in this Filter List TLV is enabled. One means enabled and zero means disabled. Other possible values are reserved.

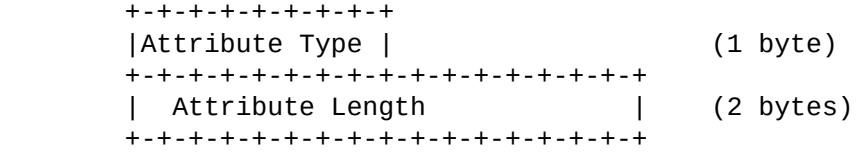
Description Length
The length of the Description Value.

Description Value
A variable ASCII string that describes the Filter List TLV (e.g., "FQDN").

Value
A variable ASCII string that specify the value of the Filter List TLV (e.g. "www.yahoo.com"). As an example, Type = 1 and Value = "www.yahoo.com" means that packets whose FQDN field equal "www.yahoo.com" match the filter item.

5.6.3. Switching to DSL Tunnel

If the RTT difference is continuously detected to violate the RTT Difference Threshold (See Section 5.2.4.) more than the times described by the RTT Difference Threshold Violation (See Section 5.2.12.), HCPE uses the Switching to DSL Tunnel attribute to inform HAG to use the DSL GRE tunnel only. When HAG receives this attribute, it MUST begin to transmit downstream traffic to this HCPE solely over the DSL GRE tunnel. The DSL GRE Tunnel Notify message MAY include the Switching to DSL Tunnel attribute.

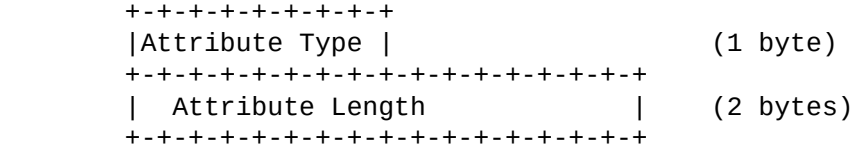


Attribute Type
Switching to DSL Tunnel, set to 11.

Attribute Length
Set to 0.

5.6.4. Overflowing to LTE Tunnel

If the RTT difference is continuously detected to not violated the RFF Difference Threshold (See Section 5.2.4.) more than the times described by the RTT Difference Compliance (See Section 5.2.13), HCPE uses the Overflowing to LTE Tunnel attribute to inform HAG that LTE GRE tunnel can be used again. The DSL GRE Tunnel Notify message MAY include the Overflowing to LTE Tunnel attribute.



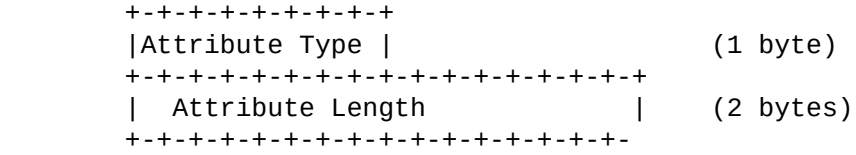
Attribute Type
Overflowing to LTE Tunnel, set to 12.

Attribute Length

Set to 0.

5.6.5. DSL Link Failure

When HCPE detects the DSL WAN interface status is down, it MUST tear down the DSL GRE tunnel. It informs HAG about the failure using the DSL Link Failure attribute. HAG MUST tear down the DSL GRE tunnel upon the DSL Link Failure attribute is received. The DSL Link Failure attribute SHOULD be carried in the LTE GRE Tunnel Notify message.

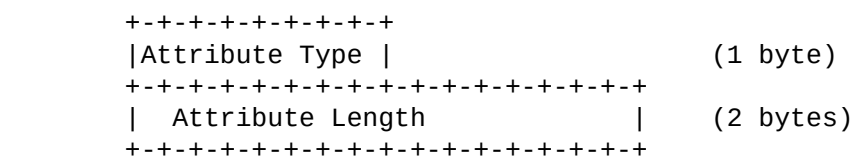


Attribute Type
DSL Link Failure, set to 18.

Attribute Length
Set to 0.

5.6.6. LTE Link Failure

When HCPE detects the LTE WAN interface status is down, it MUST tear down the LTE GRE tunnel. It informs HAG about the failure using the LTE Link Failure attribute. HAG MUST tear down the LTE GRE tunnel upon the LTE Link Failure attribute is received. The LTE Link Failure attribute SHOULD be carried in the DSL GRE Tunnel Notify message.

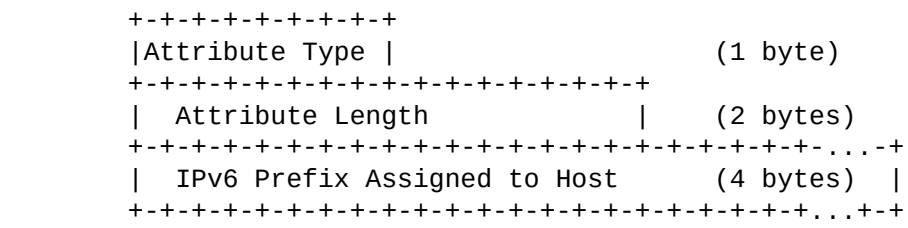


Attribute Type
LTE Link Failure, set to 19.

Attribute Length
Set to 0.

5.6.7. IPv6 Prefix Assigned to Host

If HCPE changes the IPv6 prefix assigned to the host, it uses the IPv6 Prefix Assigned to Host attribute to inform HAG. Both the LTE GRE Tunnel Notify message and the DSL GRE Tunnel Notify message MAY include the IPv6 Prefix Assigned to Host attribute.



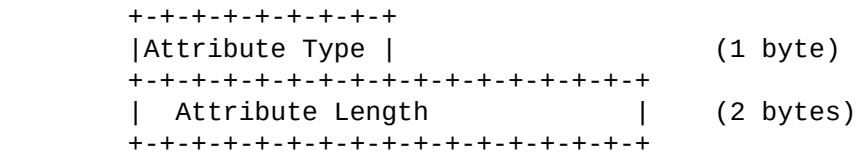
Attribute Type
   IPv6 Prefix Assigned to Host, set to 21.

Attribute Length
   Set to 17.

IPv6 Prefix Assigned to Host
   The highest-order 16 octets encode an IPv6 address. The lowest-order one octet encodes the length of a network mask. These two values are put together to represent an IPv6 prefix.

5.6.8. Diagnostic Start: Bonding Tunnel

HCPE uses the Diagnostic Start: Bonding Tunnel attribute to inform HAG to switch to diagnostic mode to test the performance of the entire bonding tunnel. The Diagnostic Start: Bonding Tunnel attribute SHOULD be carried in the DSL GRE Tunnel Notify message.

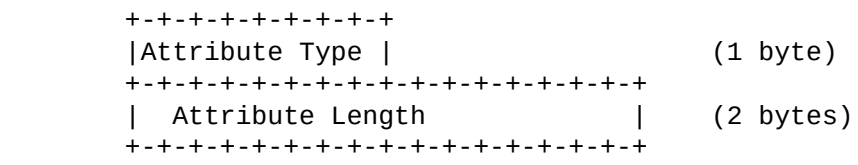


Attribute Type
   Diagnostic Start: Bonding Tunnel, set to 26.

Attribute Length
   Set to 0.

5.6.9. Diagnostic Start: DSL Tunnel

HCPE uses the Diagnostic Start: DSL Tunnel attribute to inform HAG to switch to diagnostic mode to test the performance of the DSL GRE tunnel. The Diagnostic Start: DSL Tunnel attribute SHOULD be carried in the DSL GRE Tunnel Notify message.

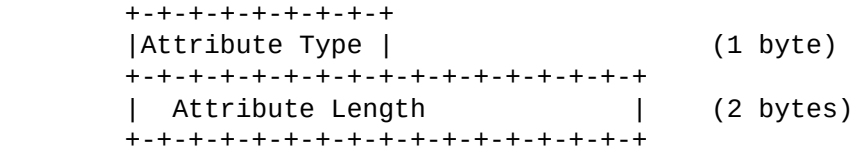


Attribute Type
Diagnostic Start: DSL Tunnel, set to 27.

Attribute Length
Set to 0.

5.6.10. Diagnostic Start: LTE Tunnel

HCPE uses the Diagnostic Start: LTE Tunnel attribute to inform HAG to switch to diagnostic mode to test the performance of the entire bonding tunnel. The Diagnostic Start: LTE Tunnel attribute SHOULD be carried in the DSL GRE Tunnel Notify message.

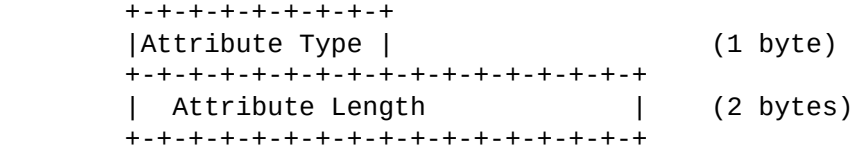


Attribute Type
Diagnostic Start: LTE Tunnel, set to 18.

Attribute Length
Set to 0.

5.6.11. Diagnostic End

HCPE uses the Diagnostic End attribute to inform HAG to stop the diagnostic mode. The Diagnostic End attribute SHOULD be carried in the DSL GRE Tunnel Notify message.

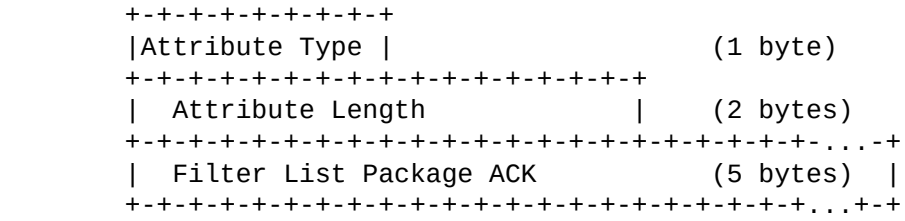


Attribute Type
Diagnostic End, set to 29.

Attribute Length
Set to 0.

5.6.12. Filter List Package ACK

HCPE uses the Filter List Package ACK attribute to acknowledge the Filter List Package sent by HAG. Both the LTE GRE Tunnel Notify message and the DSL GRE Tunnel Notify message MAY include the Filter List Package ACK attribute.



Attribute Type
Filter List Package ACK, set to 30.

Attribute Length
Set to 5.

Filter List Package ACK
The highest-order 4 octets are the Commit_Count as defined in Section 5.6.2. The lowest-order 1 octet encodes the following error codes:

0: The Filter List Package is acknowledged.
1: The Filter List Package is not acknowledged. The HCPE is a new subscriber and has not ever received a Filter List Package. In this case, HAG SHOULD tear down the bonding tunnels and force the HCPE to re-establish the GRE Tunnels.
2: The Filter List Package is not acknowledged. The HCPE has already got a valid Filter List Package. The filter list on the HCPE will continue to be used while HAG need do nothing.

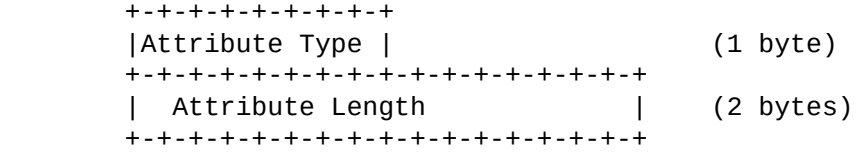
5.6.13. Switching to Active Hello State

If traffic is being sent/receive over the bonding GRE tunnels before the "No Traffic Monitored Interval" expires (See Section 5.2.15.), HCPE sends to HAG a GRE Tunnel Notify message containing the Switching to Active Hello State attribute.

HAG will switch to active hello state and send HCPE a GRE Tunnel Notify message carrying the Switching to Active Hello State attribute as the ACK.

When HCPE receives the ACK, it will switch to active hello state, start RTT detection and start sending GRE Tunnel Hello messages with

the Active Hello Interval (See Section 5.2.6.).



Attribute Type
Switching to Active Hello State, set to 33.

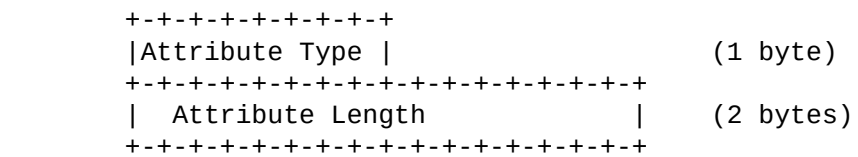
Attribute Length
Set to 0.

5.6.14. Switching to Idle Hello State

HCPE initiates switching to idle hello state when the bonding of GRE Tunnels is successfully established and the LTE GRE Tunnel Setup Accept message carrying the Idle Hello Interval attribute (See Section 5.2.14.) is received. HCPE sends to HAG a GRE Tunnel Notify message containing the Switching to Idle Hello State attribute.

HAG will switch to idle hello state, clear RTT state and send HCPE a GRE Tunnel Notify message carrying the Switching to Idle Hello State attribute as the ACK.

When HCPE receives the ACK, it will switch to idle hello state, stop RTT detection, clear RTT state as well and start sending GRE Tunnel Hello messages with the Idle Hello Interval (See Section 5.2.14).



Attribute Type
Switching to Idle Hello State, set to 34.

Attribute Length
Set to 0.

5.6.15. Tunnel Verification

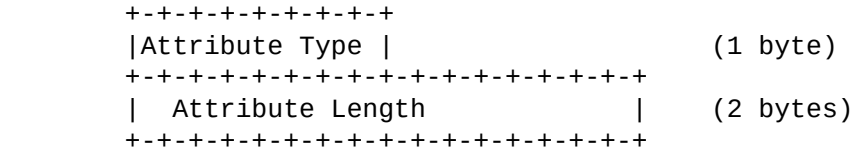
HAG uses the Tunnel Verification attribute to inform HCPE to verify whether an existing LTE GRE tunnel is still functioning. The Tunnel Verification attribute SHOULD be carried in the LTE GRE Tunnel Notify message. It provides a mean to detect the tunnel faster than the GRE

Tunnel Hello, especially when the LTE GRE tunnel is in the Idle Hello state and it takes much longer time to detect this tunnel.

When HAG receives an LTE GRE Tunnel Setup Request and finds the requested tunnel is conflicting with an existing tunnel, the HAG initiates the Tunnel Verification. The HAG drops all conflicting LTE GRE Tunnel Setup Request messages and send GRE Tunnel Notify messages carrying the Tunnel Verification attribute until the verification ends. HCPE MUST response to HAG same Tunnel Verification attribute as the ACK if the tunnel is still functioning.

If the ACK of the Tunnel Verification attribute is received from the HCPE, HAG judges that the existing tunnel is still functioning. An LTE GRE Tunnel Deny message (with Error Code = 8) will be sent to the HCPE. HCPE SHOULD terminate the GRE tunnel setup request process immediately.

If HAG does not receive a Tunnel Verification ACK message until up to 3 times (1 sending + 2 resending), it will regard the existing tunnel as failed and the LTE GRE Tunnel Setup Request will be accepted.

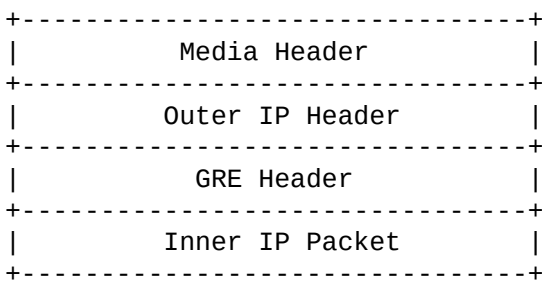


Attribute Type
Tunnel Verification, set to 35.

Attribute Length
Set to 0.

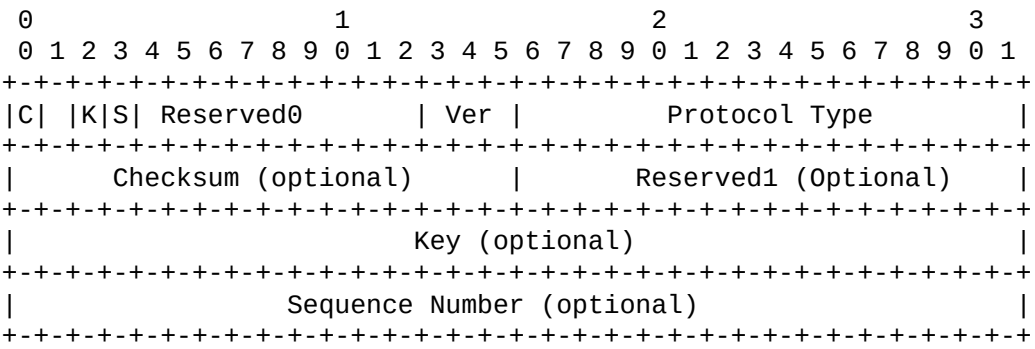
6. Tunnel Protocol Operation (Data Plane)

GRE tunnels are set up over heterogeneous connections, such as LTE and DSL, between HCPE and HAG. Users' IP (inner) packets are encapsulated in GRE packets which in turn are carried over IP (outer). The general structure of the packets is shown as below.



6.1. The GRE Header

The GRE header is first standardized in [RFC2874]. [RFC2890] adds the optional key and sequence number fields which makes the whole GRE header have the following format.



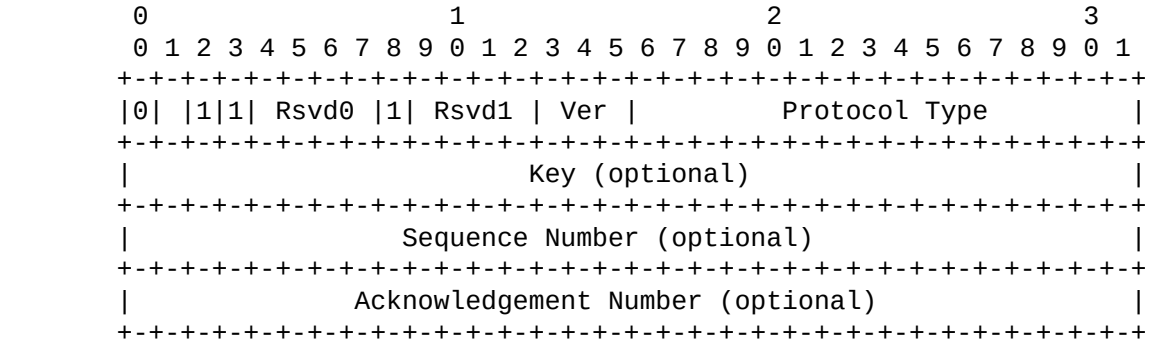
The Checksum is not used in the GRE Tunnel Bonding, therefore the C bit is set to zero.

The Key bit is set to one. For per-packet traffic distribution, the Key field is used as a 32-bit random number. It is generated by the HAG and notified to HCPE. Different from the Key filed used in control packets, each bonding of GRE tunnels gets a single Key value. HCPE MUST carry this number in each GRE header. For the per-flow traffic classification and distribution, the Key field will be used to identify the traffic flows.

The S bit is set to one and the sequence number is present for in-order delivery as per [RFC2890].

For the per-flow traffic, the GRE header need also enable the Acknowledgement Number field as used in PPTP [RFC2637]. The A bit (Bit 8) is set to one to indicate this field is present in the GRE header. This acknowledgement number and the sequence number field are used to achieve a low-level congestion and flow control. Unless explicitly pointed out, the acknowledgement number field is used as

per [RFC2637]. The enhanced GRE header has the following format:



6.2. Automatic Setup of GRE Tunnels

The HCPE gets the DSL WAN interface IP address (D) from BRAS via PPPoE, and gets the LTE WAN interface IP address (E) through PDP from PGW. The DNS resolution of HAG's domain name is requested via DSL/LTE WAN interface. The DNS server will reply with the corresponding HAG IP address (H) which MAY be pre-configured by operators.

After the interface IP addresses have been acquired, the HCPE starts the following GRE Tunnel Bonding procedure. It's REQUIRED that the HCPE first sets up the LTE GRE tunnel and then sets up the DSL GRE tunnel.

The HCPE sends the GRE Tunnel Setup Request message to HAG via the LTE WAN interface. The HAG, which receives the GRE Tunnel Setup Request message, will initiate the Authentication and Authorization procedure, as specified in [TS23.401], to check whether HCPE is being trusted by the PGW.

If the Authentication and Authorization succeed, HAG will reply to HCPE's LTE WAN interface with the GRE Tunnel Setup Accept message in which a Session ID randomly generated by the HAG is carried. Otherwise, the HAG MUST send to the HCPE's LTE WAN interface the GRE Tunnel Setup Deny message and the HCPE MUST terminate the tunnel set up process upon it receives the GRE Tunnel Setup Deny message.

After the LTE GRE tunnel is successfully set up, the HCPE will obtain the C address over the tunnel from HAG through DHCP. After that, the HCPE starts to set up the DSL GRE tunnel. It sends GRE Tunnel Setup Request message with HAG's address as the destination IP of GRE via the DSL WAN interface, carrying the aforementioned session ID received from the HAG. The HAG, which receives the GRE Tunnel Setup Request message, will initiate the Authentication and Authorization procedure in order to check whether HCPE is trusted by the BRAS.

If the Authentication and Authorization succeed, the HAG will reply to the HCPE's DSL WAN interface with the GRE Tunnel Setup Accept message. In this way, the two tunnels with the same Session ID can be used to carry traffic from the same user. That is to say, the two tunnels are "bonded" together. Otherwise, if the Authentication and Authorization fail, the HAG MUST send to the HCPE's DSL WAN interface the GRE Tunnel Setup Deny message. Meanwhile, it MUST send to the HCPE's LTE WAN interface the GRE Tunnel Tear Down message. The HCPE MUST terminate the tunnel set up process upon it receives the GRE Tunnel Setup Deny message and MUST tear down the LTE GRE tunnel that has been set up upon it receives the GRE Tunnel Tear Down Message.

7. Security Considerations

As a security feature, the Key field of the GRE header of the control messages and the data packets for the per-packet traffic distribution could be generated as a 32-bit clear-text password.

8. IANA Considerations

No IANA action is required in this document. RFC Editor: please remove this section before publication.

9. References

9.1. Normative References

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[RFC2698] Heinanen, J. and R. Guerin, "A Two Rate Three Color Marker", RFC 2698, September 1999.

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[TS23.401] "3GPP TS23.401, General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access", September 2013.

9.2. Informative References

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[RFC2724] Handelman, S., Stibler, S., Brownlee, N., and G. Ruth, "RTFM: New Attributes for Traffic Flow Measurement", RFC

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[RFC2637] Hamzeh, K., Pall, G., Verthein, W., Taarud, J., Little, W., and G. Zorn, "Point-to-Point Tunneling Protocol (PPTP)", RFC 2637, July 1999.

[RFC6320] Wadhwa, S., Moisand, J., Haag, T., Voigt, N., and T. Taylor, Ed., "Protocol for Access Node Control Mechanism in Broadband Networks", RFC 6320, October 2011.

Author’s Addresses

Nicolai Leymann
Deutsche Telekom AG
Winterfeldtstrasse 21-27
Berlin 10781
Germany

Phone: +49-170-2275345
Email: n.leymann@telekom.de

Cornelius Heidemann
Deutsche Telekom AG
Heinrich-Hertz-Strasse 3-7
Darmstadt 64295
Germany

Phone: +4961515812721
Email: heidemannc@telekom.de

Mingui Zhang
Huawei Technologies
No.156 Beiqing Rd. Haidian District,
Beijing 100095 P.R. China

EMail: zhangmingui@huawei.com

Margaret Wasserman
Painless Security

EMail: mrw@painless-security.com