Resolve IPv4 Fragmentation, MTU, MSS, and PMTUD Issues with GRE and IPsec

Contents

Introduction

This document describes how IPv4 Fragmentation and Path Maximum Transmission Unit Discovery (PMTUD) work.

Background Information

Also discussed are scenarios that involve the behavior of PMTUD when combined with different combinations of IPv4 tunnels.

IPv4 Fragmentation and Reassembly

Although the maximum length of an IPv4 datagram is 65535, most transmission links enforce a smaller maximum packet length limit, called an MTU. The MTU value depends on the transmission link.

The design of IPv4 accommodates MTU differences because it allows routers to fragment IPv4 datagrams as necessary.

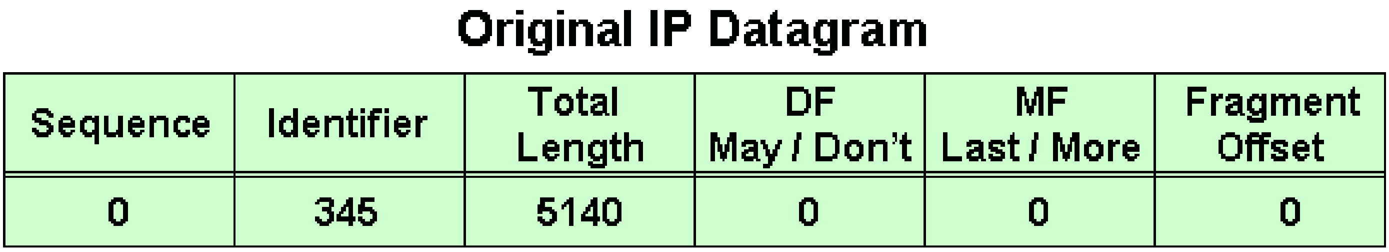
The receiving station is responsible for the reassembly of the fragments into the original, full size IPv4 datagram.

IPv4 fragmentation breaks a datagram into pieces that are reassembled later.

The IPv4 source, destination, identification, total length, and fragment offset fields, along with "more fragments" (MF) and "do not fragment" (DF) flags in the IPv4 header, are used for IPv4 fragmentation and reassembly.

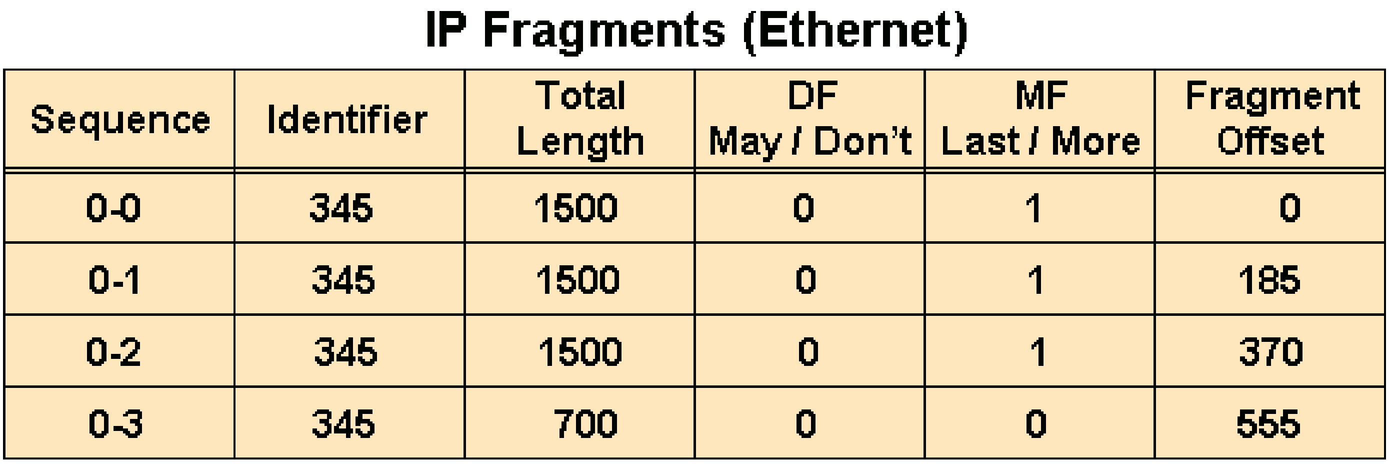
For more information about the mechanics of IPv4 fragmentation and reassembly, see RFC 791.

This image depicts the layout of an IPv4 header.



Original IP Datagram

Sequence	Identifier	Total Length	DF May / Don't	MF Last / More	Fragment Offset
0	345	5140	0	0	0



IP Fragments (Ethernet)

Sequence	Identifier	Total Length	DF May / Don't	MF Last / More	Fragment Offset
0-0	345	1500	0	1	0
0-1	345	1500	0	1	185
0-2	345	1500	0	1	370
0-3	345	700	0	0	555

The identification is 16 bits and is a value assigned by the sender of an IPv4 datagram. This aids in the reassembly of the fragments of a datagram.

The fragment offset is 13 bits and indicates where a fragment belongs in the original IPv4 datagram. This value is a multiple of 8 bytes.

There are 3 bits for control flags in the flags field of the IPv4 header. The "do not fragment" (DF) bit determines whether or not a packet is allowed to be fragmented.

Bit 0 is reserved and is always set to 0.

Bit 1 is the DF bit (0 = "can fragment", 1 = "do not fragment").

Bit 2 is the MF bit (0 = "last fragment," 1 = "more fragments").

Value	**Bit 0 Reserved**	**Bit 1 DF**	**Bit 2 MF**
0	0	May	Last
1	0	Do not	More

If the lengths of the IPv4 fragments are added, the value exceeds the original IPv4 datagram length by 60.

The reason that the overall length is increased by 60 is because three additional IPv4 headers were created, one for each fragment after the first fragment.

The first fragment has an offset of 0, the length of this fragment is 1500; this includes 20 bytes for the slightly modified original IPv4 header.

The second fragment has an offset of 185 (185 x 8 = 1480); the data portion of this fragment starts 1480 bytes into the original IPv4 datagram.

The length of this fragment is 1500; this includes the additional IPv4 header created for this fragment.

The third fragment has an offset of 370 (370 x 8 = 2960); the data portion of this fragment starts 2960 bytes into the original IPv4 datagram.

The length of this fragment is 1500; this includes the additional IPv4 header created for this fragment.

The fourth fragment has an offset of 555 (555 x 8 = 4440), which means that the data portion of this fragment starts 4440 bytes into the original IPv4 datagram.

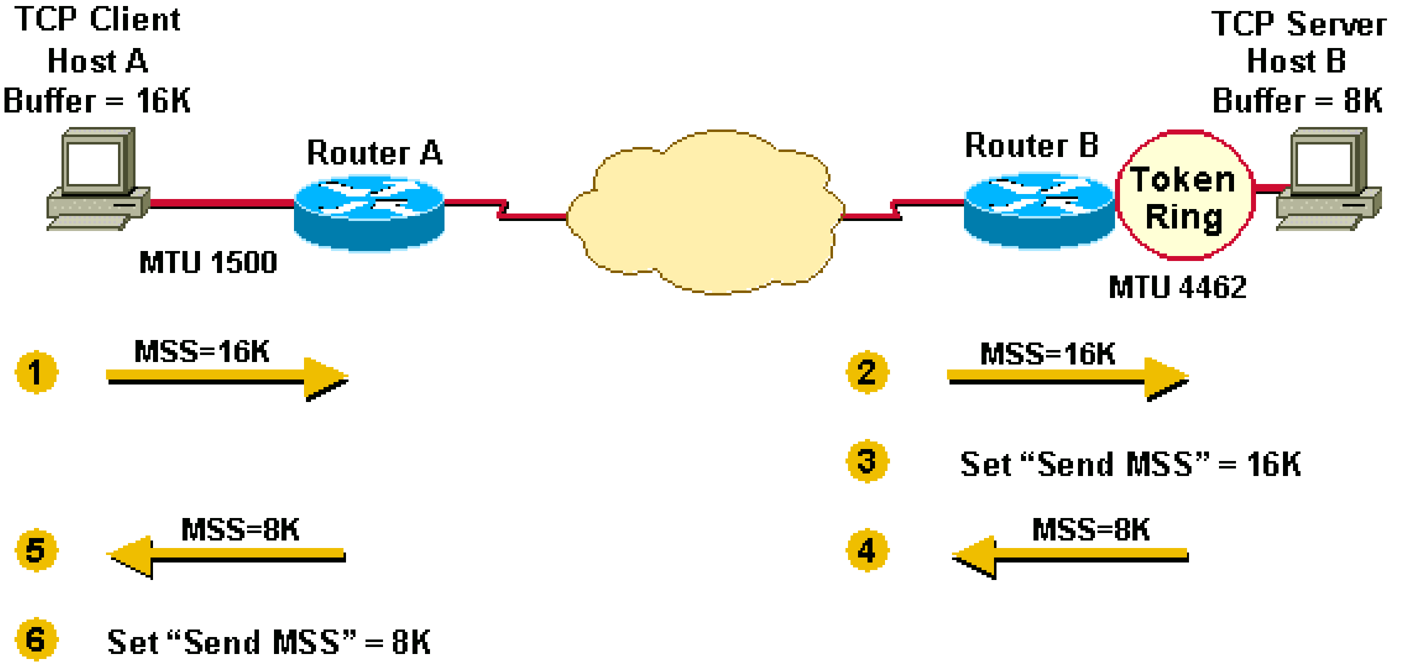
The length of this fragment is 700 bytes; this includes the additional IPv4 header created for this fragment.

It is only when the last fragment is received that the size of the original IPv4 datagram can be determined.

The fragment offset in the last fragment (555) gives a data offset of 4440 bytes into the original IPv4 datagram.

The sum of the data bytes from the last fragment (680 = 700 - 20) yields 5120 bytes, which is the data portion of the original IPv4 datagram.

The addition of 20 bytes for an IPv4 header equals the size of the original IPv4 datagram (4440 + 680 + 20 = 5140) as shown in the images.



Issues with IPv4 Fragmentation

IPv4 fragmentation results in a small increase in CPU and memory overhead to fragment an IPv4 datagram.

This is true for the sender and for a router in the path between a sender and a receiver.

The creation of fragments involves the creation of fragment headers and copies the original datagram into the fragments.

This is done efficiently because the information needed to create the fragments is immediately available.

Fragmentation causes more overhead for the receiver when reassembling the fragments because the receiver must allocate memory for the arriving fragments and coalesce them back into one datagram after all of the fragments are received.

Reassembly on a host is not considered a problem because the host has the time and memory resources to devote to this task.

Reassembly, however, is inefficient on a router whose primary job is to forward packets as quickly as possible.

A router is not designed to hold on to packets for any length of time.

A router that does the reassembly chooses the largest buffer available (18K), because it has no way to determine the size of the original IPv4 packet until the last fragment is received.

Another fragmentation issue involves how dropped fragments are handled.

If one fragment of an IPv4 datagram is dropped, then the entire original IPv4 datagram must be present and it is also fragmented.

This is seen with Network File System (NFS). NFS has a read and write block size of 8192.

Therefore, a NFS IPv4/UDP datagram is approximately 8500 bytes (which includes NFS, UDP, and IPv4 headers).

A sending station connected to an Ethernet (MTU 1500) has to fragment the 8500-byte datagram into six (6) pieces; Five (5) 1500 byte fragments and one (1) 1100 byte fragment.

If any of the six fragments are dropped because of a congested link, the complete original datagram has to be retransmitted. This results in six more fragments to be created.

If this link drops one in six packets, then the odds are low that any NFS data are transferred over this link, because at least one IPv4 fragment would be dropped from each NFS 8500-byte original IPv4 datagram.

Firewalls that filter or manipulate packets based on Layer 4 (L4) through Layer 7 (L7) information have trouble processing IPv4 fragments correctly.

If the IPv4 fragments are out of order, a firewall blocks the non-initial fragments because they do not carry the information that match the packet filter.

This means that the original IPv4 datagram could not be reassembled by the receiving host.

If the firewall is configured to allow non-initial fragments with insufficient information to properly match the filter, a non-initial fragment attack through the firewall is possible.

Network devices such as Content Switch Engines direct packets based on L4 through L7 information, and if a packet spans multiple fragments, then the device has trouble enforcing its policies.

Avoid IPv4 Fragmentation: How TCP MSS Works

The Transmission Control Protocol (TCP) Maximum Segment Size (MSS) defines the maximum amount of data that a host accepts in a single TCP/IPv4 datagram.

This TCP/IPv4 datagram is possibly fragmented at the IPv4 layer. The MSS value is sent as a TCP header option only in TCP SYN segments.

Each side of a TCP connection reports its MSS value to the other side. The MSS value is *not* negotiated between hosts.

The sending host is required to limit the size of data in a single TCP segment to a value less than or equal to the MSS reported by the receiving host.

Originally, MSS meant how big a buffer (greater than or equal to 65496 bytes) was allocated on a receiving station to be able to store the TCP data contained within a single IPv4 datagram.

MSS was the maximum segment of data that the TCP receiver was ing to accept. This TCP segment could be as large as 64K and fragmented at the IPv4 layer in order to be transmitted to the receiving host.

The receiving host would reassemble the IPv4 datagram before it handed the complete TCP segment to the TCP layer.

How MSS values are set and used to limit TCP segment and IPv4 datagram sizes.

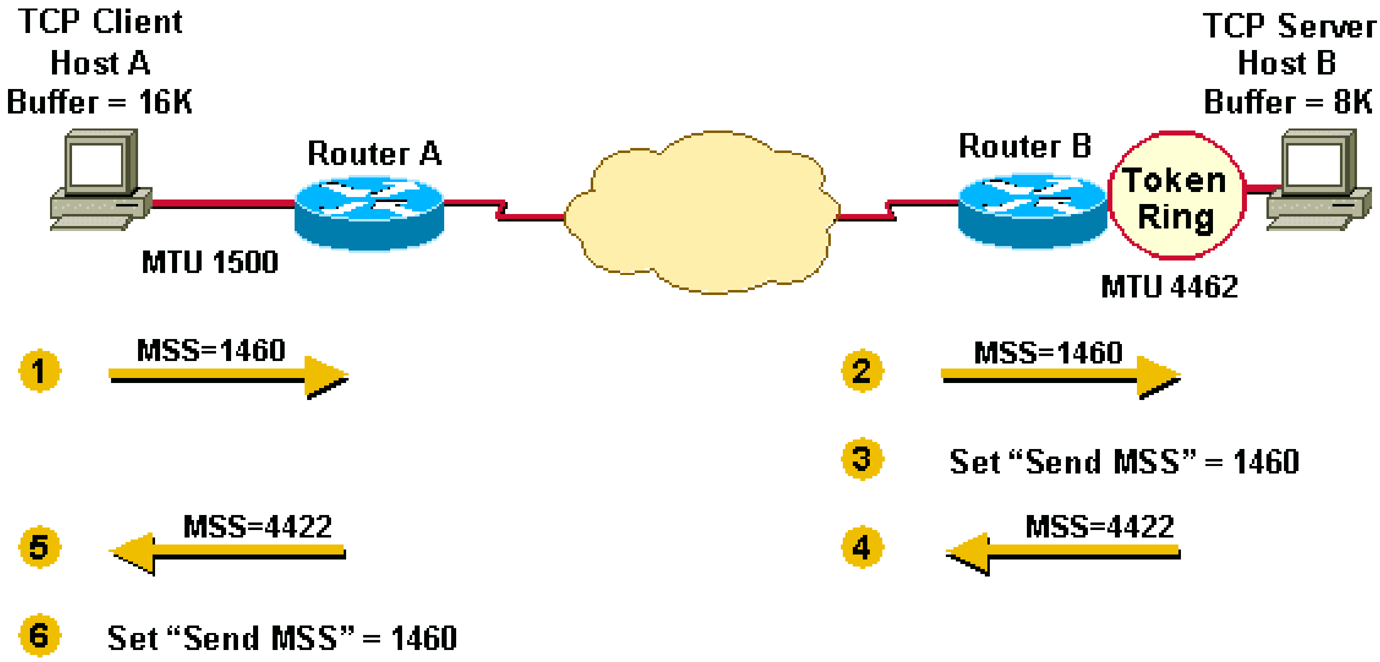
Example 1 illustrates the way MSS was first implemented.

Host A has a buffer of 16K and Host B a buffer of 8K. They send and receive their MSS values and adjust their send MSS for sending data to each other.

Host A and Host B have to fragment the IPv4 datagrams that are larger than the interface MTU, yet less than the send MSS because the TCP stack passes 16K or 8K bytes of data down the stack to IPv4.

In the case of Host B, packets are fragmented to get onto the Token Ring LAN and again to get onto the Ethernet LAN.

Example 1



1. Host A sends its MSS value of 16K to Host B.
2. Host B receives the 16K MSS value from Host A.
3. Host B sets its send MSS value to 16K.
4. Host B sends its MSS value of 8K to Host A.
5. Host A receives the 8K MSS value from Host B.
6. Host A sets its send MSS value to 8K.

To assist in avoiding IPv4 fragmentation at the endpoints of the TCP connection, the selection of the MSS value was changed to the minimum buffer size and the MTU of the outgoing interface (- 40).

MSS numbers are 40 bytes smaller than MTU numbers because MSS (the TCP data size) does not include the 20-byte IPv4 header and the 20-byte TCP header.

MSS is based on default header sizes; the sender stack must subtract the appropriate values for the IPv4 header and the TCP header depends on what TCP or IPv4 options are used.

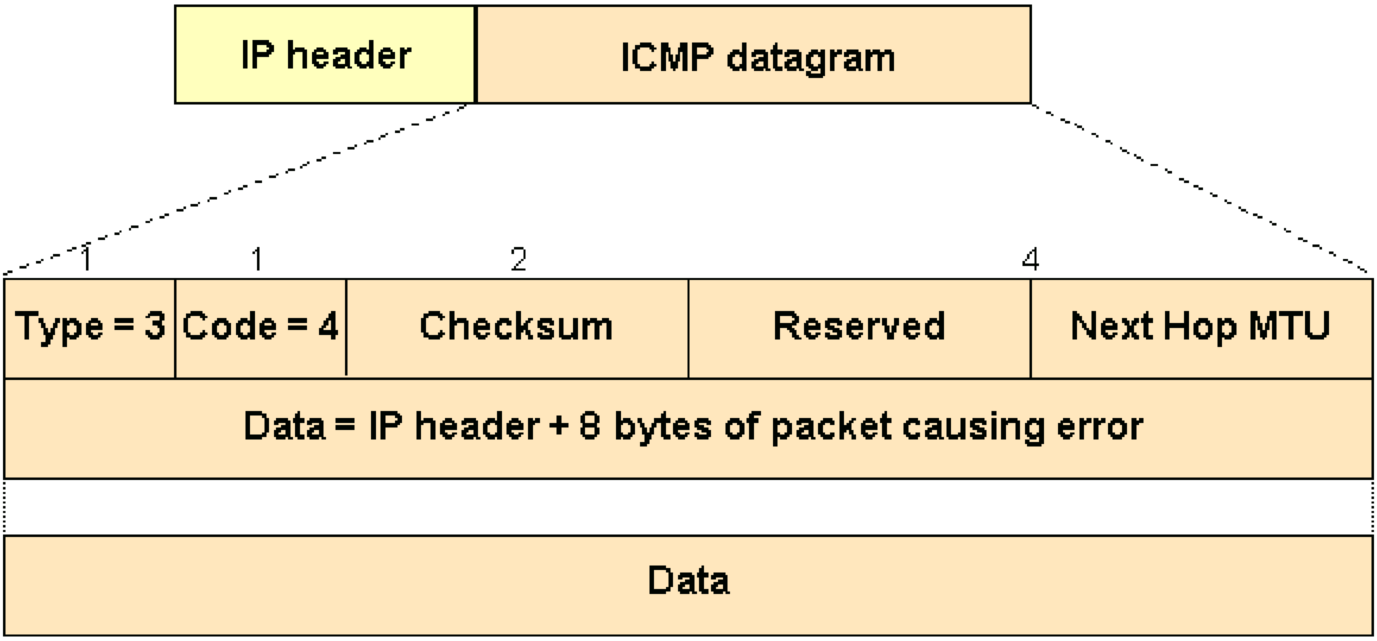
MSS currently works in a manner where each host first compares its outgoing interface MTU with its own buffer and chooses the lowest value as the MSS to send.

The hosts then compare the MSS size received against their own interface MTU and again choose the lower of the two values.

Example 2 illustrates this additional step taken by the sender in order to avoid fragmentation on the local and remote wires.

The MTU of the outgoing interface is taken into account by each host before the hosts send each other their MSS values. This helps to avoid fragmentation.

Example 2



1. Host A compares its MSS buffer (16K) and its MTU (1500 - 40 = 1460) and uses the lower value as the MSS (1460) to send to Host B.
2. Host B receives the send MSS (1460) from Host A and compares it to the value of its outbound interface MTU - 40 (4422).
3. Host B sets the lower value (1460) as the MSS in order to send IPv4 datagrams to Host A.

4. Host B compares its MSS buffer (8K) and its MTU (4462-40 = 4422) and uses 4422 as the MSS to send to Host A.
5. Host A receives the send MSS (4422) from Host B and compares it to the value of its outbound interface MTU -40 (1460).
6. Host A sets the lower value (1460) as the MSS for sending IPv4 datagrams to Host B.

1460 is the value chosen by both hosts as the send MSS for each other. Often, the send MSS value are the same on each end of a TCP connection.

In Example 2, fragmentation does not occur at the endpoints of a TCP connection because both outgoing interface MTUs are taken into account by the hosts.

Packets still become fragmented in the network between Router A and Router B if they encounter a link with a lower MTU than that of either hosts' outbound interface.

What is PMTUD

TCP MSS addresses fragmentation at the two endpoints of a TCP connection, but it does not handle cases where there is a smaller MTU link in the middle between these two endpoints.

PMTUD was developed in order to avoid fragmentation in the path between the endpoints. It is used to dynamically determine the lowest MTU along the path from a packet source to its destination.

> **Note**: PMTUD is only supported by TCP and UDP. Other protocols do not support it. If PMTUD is enabled on a host, all TCP and UDP packets from the host have the DF bit set.

When a host sends a full MSS data packet with the DF bit set, PMTUD reduces the send MSS value for the connection if it receives information that the packet would require fragmentation.

A host records the MTU value for a destination because it creates a host (/32) entry in its routing table with this MTU value.

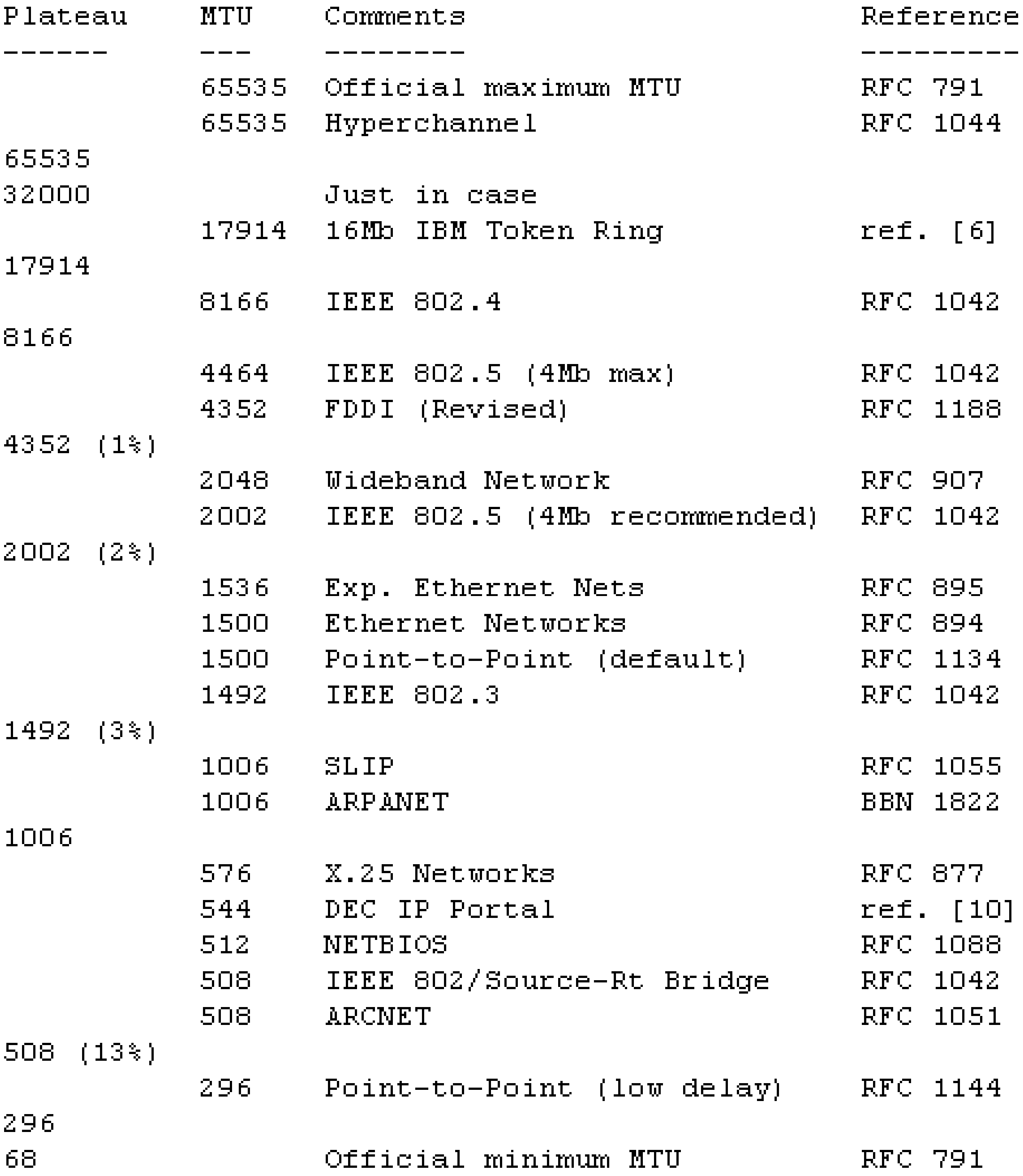
If a router attempts to forward an IPv4 datagram (with the DF bit set) onto a link that has a lower MTU than the size of the packet, the router drops the packet and returns an Internet Control Message Protocol (ICMP) "Destination Unreachable" message to the IPv4 datagram source with the code that indicates "fragmentation needed and DF set" (type 3, code 4).

When the source station receives the ICMP message, it lowers the send MSS, and when TCP retransmits the segment, it uses the smaller segment size.

Here is an example of an ICMP "fragmentation needed and DF set" message seen on a router after the **debug ip icmp** command is turned on:

```
ICMP: dst (10.10.10.10) frag. needed and DF set
unreachable sent to 10.1.1.1
```

This diagram shows the format of ICMP header of a "fragmentation needed and DF set" "Destination Unreachable" message.



Plateau	MTU	Comments	Reference
------	---	---------	----------
	65535	Official maximum MTU	RFC 791
	65535	Hyperchannel	RFC 1044
65535			
32000		Just in case	
	17914	16Mb IBM Token Ring	ref. [6]
17914			
	8166	IEEE 802.4	RFC 1042
8166			
	4464	IEEE 802.5 (4Mb max)	RFC 1042
	4352	FDDI (Revised)	RFC 1188
4352 (1%)			
	2048	Wideband Network	RFC 907
	2002	IEEE 802.5 (4Mb recommended)	RFC 1042
2002 (2%)			
	1536	Exp. Ethernet Nets	RFC 895
	1500	Ethernet Networks	RFC 894
	1500	Point-to-Point (default)	RFC 1134
	1492	IEEE 802.3	RFC 1042
1492 (3%)			
	1006	SLIP	RFC 1055
	1006	ARPANET	BBN 1822
1006			
	576	X.25 Networks	RFC 877
	544	DEC IP Portal	ref. [10]
	512	NETBIOS	RFC 1088
	508	IEEE 802/Source-Rt Bridge	RFC 1042
	508	ARCNET	RFC 1051
508 (13%)			
	296	Point-to-Point (low delay)	RFC 1144
296			
68		Official minimum MTU	RFC 791

Per RFC 1191, a router that returns an ICMP message which indicates "fragmentation needed and DF set" must include the MTU of that next-hop network in the low-order 16 bits of the ICMP additional header field that is labeled "unused" in the ICMP specification RFC 792.

Early implementations of RFC 1191 did not supply the next hop MTU information. Even when this information was supplied, some hosts ignore it.

For this case, RFC 1191 also contains a table that lists the suggested values by which the MTU is lowered during PMTUD.

It is used by hosts in order to arrive more quickly at a reasonable value for the send MSS and as shown in this example.

PMTUD is continually performed on all packets because the path between sender and receiver can change dynamically.

Each time a sender receives a "Cannot Fragment" ICMP messages, it updates the routing information (where it stores the PMTUD).

Two possible things can happen during PMTUD:

1. The packet can get all the way to the receiver without being fragmented.

> **Note**: In order for a router to protect the CPU against DoS attacks, it throttles the number of ICMP unreachable messages that it would send, to two per second. Therefore, in this context, if you have a network scenario in which you expect that the router would need to respond with more than two ICMP messages (type = 3, code = 4) per second (can be different hosts), disable the throttling of ICMP messages with the **no ip icmp rate-limit unreachable [df] interface** command.

---

2. The sender gets ICMP "Cannot Fragment" messages from hops along the path to the receiver.

PMTUD is done independently for both directions of a TCP flow.

There are cases where PMTUD in one direction of a flow triggers one of the end stations to lower the send MSS and the other end station keeps the original send MSS because it never sent an IPv4 datagram large enough to trigger PMTUD.

An example is the HTTP connection depicted in Example 3. The TCP client sends small packets and the server sends large packets.

In this case, only the large packets from the server (greater than 576 bytes) trigger PMTUD.

The packets from the client are small (less than 576 bytes) and do not trigger PMTUD because they do not require fragmentation to get across the 576 MTU link.

Example 3

Example 4 shows an asymmetric routing example where one of the paths has a smaller minimum MTU than the other.

Asymmetric routing occurs when different paths are taken to send and receive data between two endpoints.

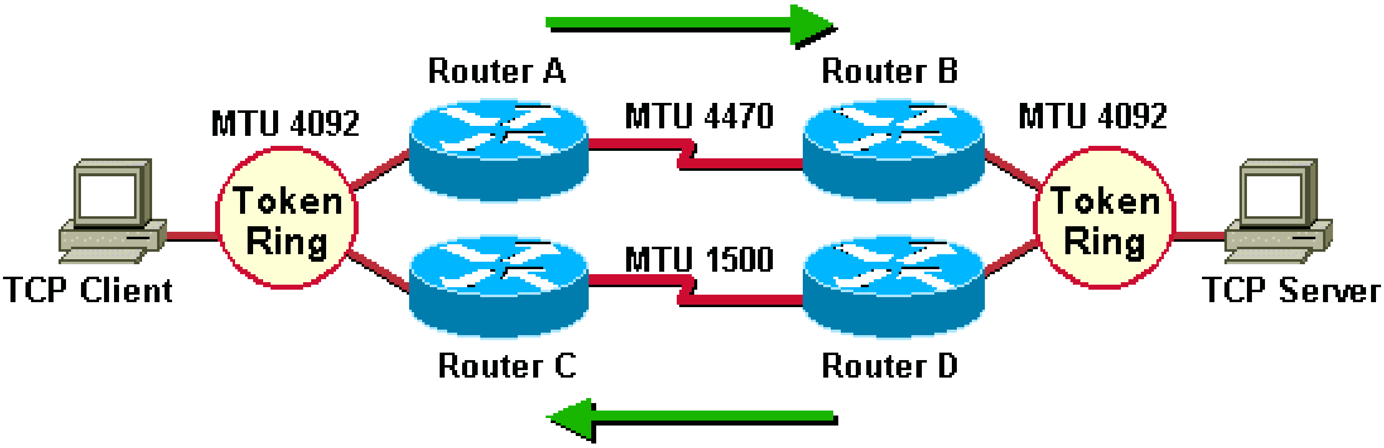
In this example, PMTUD triggers the lowering of the send MSS only in one direction of a TCP flow.

The traffic from the TCP client to the server flows through Router A and Router B, whereas the return traffic that comes from the server to the client flows through Router D and Router C.

When the TCP server sends packets to the client, PMTUD triggers the server to lower the send MSS because Router D must fragment the 4092 byte packets before it can send them to Router C.

Conversely, The client never receives an ICMP "Destination Unreachable" message with the code that indicates "fragmentation needed and DF set" because Router A does not have to fragment packets when it sends them to the server through Router B.

Example 4



Note: The **ip tcp path-mtu-discovery** command is used in order to enable TCP MTU path discovery for TCP connections initiated by routers (BGP and Telnet for example).

Problems with PMTUD

These are things that can break PMTUD.

- A router drops a packet and does not send an ICMP message. (Uncommon)
- A router generates and sends an ICMP message, but the ICMP message gets blocked by a router or firewall between this router and the sender. (Common)
- A router generates and sends an ICMP message, but the sender ignores the message. (Uncommon)

The first and last of the three bullets here are usually the result of an error, but the middle bullet describes a common problem.

Those that implement ICMP packet filters tend to block all ICMP message types rather than to block only certain ICMP message types.

It is possible for packet filter to block all ICMP message types except those that are "unreachable" or "time-exceeded."

The success or failure of PMTUD hinges upon ICMP unreachable messages that get through to the sender of a TCP/IPv4 packet.

ICMP time-exceeded messages are important for other IPv4 issues.

An example of such a packet filter, implemented on a router is shown here.

```
access-list 101 permit icmp any any unreachable
access-list 101 permit icmp any any time-exceeded
access-list 101 deny icmp any any
access-list 101 permit ip any any
```

There are other techniques that can be used to alleviate the problem of a completely blocked ICMP.

- Clear the DF bit on the router and allow fragmentation. (This is not a good idea, though. See Issues with IP Fragmentation for more information).
- Manipulate the TCP MSS option value MSS with the interface command **ip tcp adjust-mss <500-1460>**.

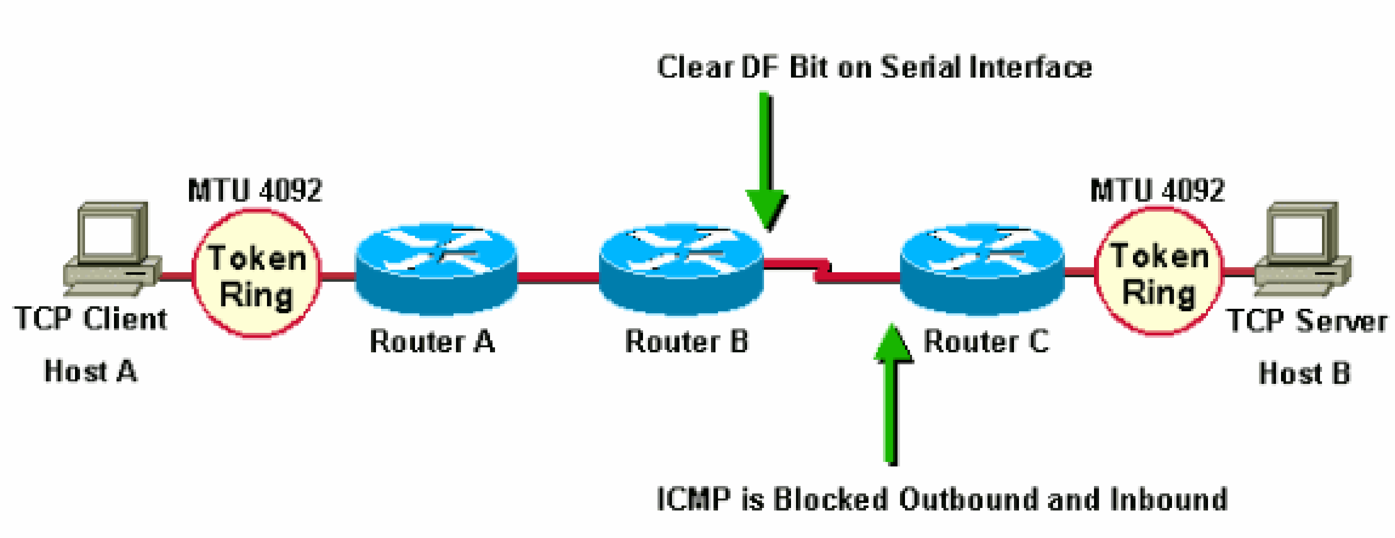
In the next example, Router A and Router B are in the same administrative domain. Router C is inaccessible and blocks ICMP, so PMTUD is broken.

A workaround for this situation is to clear the DF bit in both directions on Router B in order to allow fragmentation. This can be done with policy routing.

The syntax to clear the DF bit is available in Cisco IOS® Software Release 12.1(6) and later.

```
interface serial0
...
ip policy route-map clear-df-bit
route-map clear-df-bit permit 10
    match ip address 111
    set ip df 0

access-list 111 permit tcp any any
```



Another option is to change the TCP MSS option value on SYN packets that traverse the router (available in Cisco IOS® 12.2(4)T and later).

This reduces the MSS option value in the TCP SYN packet so that it is smaller than the value (1460) in the **ip tcp adjust-mss**command.

The result is that the TCP sender sends segments no larger than this value.

The IPv4 packet size is 40 bytes larger (1500) than the MSS value (1460 bytes) in order to account for the TCP header (20 bytes) and the IPv4 header (20 bytes).

You can adjust the MSS of TCP SYN packets with the **ip tcp adjust-mss** command. This syntax reduces the MSS value on TCP segments to 1460.

This command effects traffic both inbound and outbound on interface serial0.

```
int s0
ip tcp adjust-mss 1460
```

IPv4 fragmentation issues have become more widespread since IPv4 tunnels have become more widely deployed.

Tunnels cause more fragmentation because the tunnel encapsulation adds "overhead" to the size of a packet.

For example, the addition of Generic Router Encapsulation (GRE) adds 24 bytes to a packet, and after this increase, the packet needs to be fragmented because it is larger than the outbound MTU.

Common Network Topologies that Need PMTUD

PMTUD is needed in network situations where intermediate links have smaller MTUs than the MTU of the end links. Some common reasons for the existence of these smaller MTU links are:

- Token Ring (or FDDI)-connected end hosts with an Ethernet connection between them. The Token Ring (or FDDI) MTUs at the ends are greater than the Ethernet MTU in the middle.
- PPPoE (often used with ADSL) needs 8 bytes for its header. This reduces the effective MTU of the Ethernet to 1492 (1500 - 8).

Tunnel protocols like GRE, IPv4sec, and L2TP also need space for their respective headers and trailers. This also reduces the effective MTU of the outbound interface.

Tunnel

A tunnel is a logical interface on a Cisco router that provides a way to encapsulate passenger packets inside a transport protocol.

It is an architecture designed to provide services in order to implement a point-to-point encapsulation scheme. Tunnel interfaces have these three primary components:

- Passenger protocol (AppleTalk, Banyan VINES, CLNS, DECnet, IPv4, or IPX)
- Carrier protocol - One of these encapsulation protocols:
    - GRE - Cisco multiprotocol carrier protocol. See RFC 2784 and RFC 1701 for more information.
    - IPv4 in IPv4 tunnels - See RFC 2003 for more information.

- Transport protocol - The protocol used to carry the encapsulated protocol.

The packets shown in this section illustrate the IPv4 tunneling concepts where GRE is the encapsulation protocol and IPv4 is the transport protocol.

The passenger protocol is also IPv4. In this case, IPv4 is both the transport and the passenger protocol.

Normal Packet

IPv4	TCP	Telnet

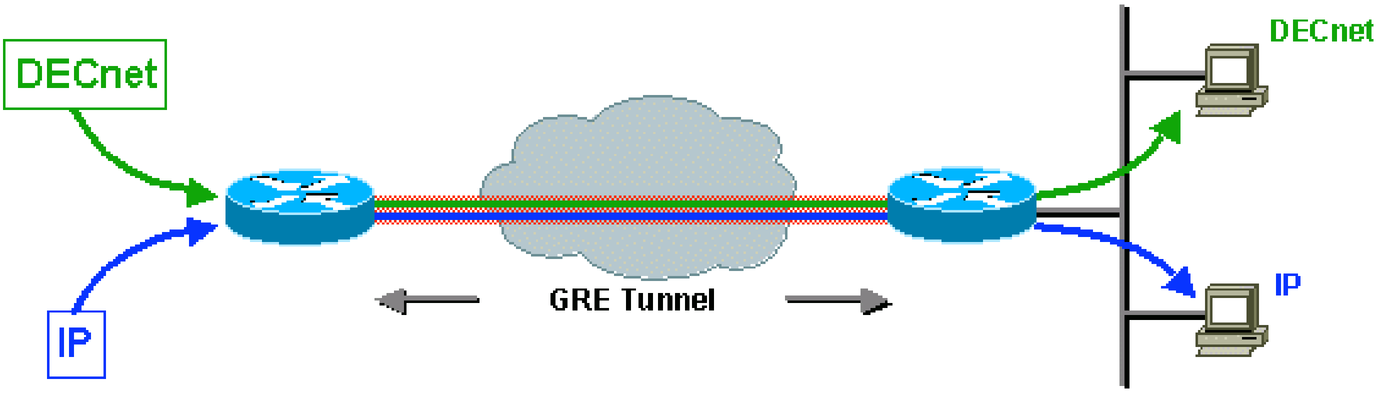
Tunnel Packet

IPv4	GRE	IPv4	TCP	Telnet

- IPv4 is the transport protocol.
- GRE is the encapsulation protocol.
- IPv4 is the passenger protocol.

The next example shows the encapsulation of IPv4 and DECnet as passenger protocols with GRE as the carrier.

This illustrates the possibility that carrier protocols encapsulate multiple passenger protocols as shown in the image.



A network administrator considers tunneling in a situation where there are two discontiguous non-IPv4 networks separated by an IPv4 backbone.

If the discontiguous networks run DECnet, the administrator can opt to connect them together (or not to) by configuring DECnet in the backbone.

The administrator does not want to permit DECnet routing to consume backbone bandwidth because this could interfere with the performance of the IPv4 network.

A viable alternative is to tunnel DECnet over the IPv4 backbone. The tunnel solution encapsulates the DECnet packets inside IPv4, and sends them across the backbone to the tunnel endpoint where the encapsulation is removed and the DECnet packets are routed to their destination via DECnet.

There are advantages to encapsulate traffic inside another protocol:

- The endpoints use private addresses (RFC 1918) and the backbone does not support routing these addresses.

- Allow Virtual Private Networks (VPNs) across WANs or the Internet.
- Join together discontiguous multiprotocol networks over a single-protocol backbone.
- Encrypt traffic over the backbone or Internet.

Hereafter, IPv4 is used as the passenger protocol and IPv4 as the transport protocol.

Considerations Regarding Tunnel Interfaces

These are considerations when tunneling.

- Fast switching of GRE tunnels was introduced in Cisco IOS® Release 11.1 and CEF switching was introduced in version 12.0.
- CEF switching for multipoint GRE tunnels was introduced in version 12.2(8)T.
- Encapsulation and decapsulation at tunnel endpoints were slow operations in earlier versions of Cisco IOS® when only process switching was supported.
- There are security and topology issues when tunneling packets. Tunnels can bypass Access Control Lists (ACLs) and firewalls.
- If you tunnel through a firewall, you bypass the passenger protocol being tunneled. Therefore, it is recommended to include firewall functionality at the tunnel endpoints in order to enforce any policy on the passenger protocols.
- Tunneling creates problems with transport protocols that have limited timers (for example, DECnet) because of increased latency.
- Tunneling across environments with different speed links, like fast FDDI rings and through slow 9600-bps phone lines, introduces packet reordering problems. Some passenger protocols function poorly in mixed media networks.
- Point-to-point tunnels consume bandwidth on a physical link. Over multiple point-to-point tunnels, each tunnel interface has a bandwidth and that the physical interface over which the tunnel runs has a bandwidth. For example, set the tunnel bandwidth to 100 Kb if there were 100 tunnels running over a 10 Mb link. The default bandwidth for a tunnel is 9Kb.
- Routing protocols prefer a tunnel over a real link because the tunnel deceptively appears to be a one-hop link with the lowest cost path, although it involves more hops and therefore more costly than another path. This is mitigated with proper configuration of the routing protocol. Consider running a different routing protocol over the tunnel interface than the routing protocol running on the physical interface.
- Problems with recursive routing are avoided by configuring appropriate static routes to the tunnel destination. A recursive route is when the best path to the tunnel destination is through the tunnel itself. This situation causes the tunnel interface to bounce up and down. This error is seen when there is a recursive routing problem.

```
%TUN-RECURDOWN Interface Tunnel 0
temporarily disabled due to recursive routing
```

Router as PMTUD Participant at Endpoint of Tunnel

The router has two different PMTUD roles to play when it is the endpoint of a tunnel.

- In the first role, the router is the forwarder of a host packet. For PMTUD processing, the router needs to check the DF bit and packet size of the original data packet and take appropriate action when necessary.
- The second role comes into play after the router has encapsulated the original IPv4 packet inside the tunnel packet. At this stage, the router acts more like a host with respect to PMTUD and in regards to the tunnel IPv4 packet.

When the router acts in the first role (a router that forwards host IPv4 packets), this role comes into play before the router encapsulates the host IPv4 packet inside the tunnel packet.

If the router participates as the forwarder of a host packet, it completes these actions:

- Check whether the DF bit is set.
- Check what size packet the tunnel can accommodate.
- Fragment (if packet is too large and DF bit is not set), encapsulate fragments and send; or
- Drop the packet (if packet is too large and DF bit is set) and send an ICMP message to the sender.
- Encapsulate (if packet is not too large) and send.

Generically, there is a choice of encapsulation and then fragmentation (send two encapsulation fragments) or fragmentation and then encapsulation (send two encapsulated fragments).

Two examples that show the interaction of PMTUD and packets that traverse example networks are detailed in this section.

The first example shows what happens to a packet when the router (at the tunnel source) acts in the role of forwarding router.

To process PMTUD, the router needs to check the DF bit and packet size of the original data packet and take appropriate action.

This examples uses GRE encapsulation for the tunnel. GRE does fragmentation before encapsulation.

Later examples show scenarios in which fragmentation is done after encapsulation.

In Example 1, the DF bit is not set (DF = 0) and the GRE tunnel IPv4 MTU is 1476 (1500 - 24).

Example 1

1. The forwarding router (at the tunnel source) receives a 1500-byte datagram with the DF bit clear (DF = 0) from the sending host.

This datagram is composed of a 20-byte IP header plus a 1480 byte TCP payload.

IPv4	1480 bytes TCP + data

2. Because the packet is too large for the IPv4 MTU after the GRE overhead (24 bytes) is added, the forwarding router breaks the datagram into two fragments of 1476 (20 bytes IPv4 header + 1456 bytes IPv4 payload) and 44 bytes (20 bytes of IPv4 header + 24 bytes of IPv4 payload)

After the GRE encapsulation is added, the packet is not larger than the outgoing physical interface MTU.

IP$_0$	1456 bytes TCP + data
IP$_1$	24 bytes data

3. The forwarding router adds GRE encapsulation, which includes a 4-byte GRE header plus a 20-byte IPv4 header, to each fragment of the original IPv4 datagram.

These two IPv4 datagrams now have a length of 1500 and 68 bytes and these datagrams are seen as individual IPv4 datagrams, not as fragments.

IPv4	GRE	IP$_0$	1456 bytes TCP + data
IPv4	GRE	IP$_1$	24 bytes data

4. The tunnel destination router removes the GRE encapsulation from each fragment of the original datagram, which leaves two IPv4 fragments of lengths 1476 and 24 bytes.

These IPv4 datagram fragments are forwarded separately by this router to the receiving host.

IP$_0$	1456 bytes TCP + data
IP$_1$	24 bytes data

5. The receiving host reassembles these two fragments into the original datagram.

IPv4	1480 bytes TCP + data

Example 2 depicts the role of the forwarding router in the context of a network topology.

The router acts in the same role of forwarding router, but this time the DF bit is set (DF = 1).

Example 2

1. The forwarding router at the tunnel source receives a 1500-byte datagram with DF = 1 from the sending host.

IPv4	1480 bytes TCP + data

2. Since the DF bit is set, and the datagram size (1500 bytes) is greater than the GRE tunnel IPv4 MTU (1476), the router drops the datagram and send an "ICMP fragmentation needed but DF bit set" message to the source of the datagram.

The ICMP message alerts the sender that the MTU is 1476.

IPv4	ICMP MTU 1476

3. The sending host receives the ICMP message, and when it resends the original data it uses a 1476-byte IPv4 datagram.

IPv4	1456 bytes TCP + data

4. This IPv4 datagram length (1476 bytes) is now equal in value to the GRE tunnel IPv4 MTU so the router adds the GRE encapsulation to the IPv4 datagram.

IPv4	GRE	IPv4	1456 bytes TCP + data

5. The receiving router (at the tunnel destination) removes the GRE encapsulation of the IPv4 datagram and sends it to the receiving host.

IPv4	1456 bytes TCP + data

This is what happens when the router acts in the second role as a sending host with respect to PMTUD and in regards to the tunnel IPv4 packet.

This role comes into play after the router has encapsulated the original IPv4 packet inside the tunnel packet.

> **Note**: By default, a router does not perform PMTUD on the GRE tunnel packets that it generates. The **tunnel path-mtu-discovery** command can be used to turn on PMTUD for GRE-IPv4 tunnel packets.

Example 3 shows what happens when the host sends IPv4 datagrams that are small enough to fit within the IPv4 MTU on the GRE Tunnel interface.

The DF bit in this case can be either set or clear (1 or 0).

The GRE tunnel interface does not have the **tunnel path-mtu-discovery** command configured so the router dies not PMTUD on the GRE-IPv4 packet.

Example 3

1. The forwarding router at the tunnel source receives a 1476-byte datagram from the sending host.

IPv4	1456 bytes TCP + data

2. This router encapsulates the 1476-byte IPv4 datagram inside GRE to get a 1500-byte GRE IPv4 datagram.

The DF bit in the GRE IPv4 header is cleared (DF = 0). This router then forwards this packet to the tunnel destination.

IPv4	GRE	IPv4	1456 bytes TCP + data

3. Assume there is a router between the tunnel source and destination with a link MTU of 1400.

This router fragments the tunnel packet since the DF bit is clear (DF = 0).

Remember that this example fragments the outermost IPv4, so the GRE, inner IPv4, and TCP headers only show up in the first fragment.

IP$_0$	GRE	IP	1352 bytes TCP + data
IP$_1$	104 bytes data		

4. The tunnel destination router must reassemble the GRE tunnel packet.

IP	GRE	IP	1456 bytes TCP + data

5. After the GRE tunnel packet is reassembled, the router removes the GRE IPv4 header and sends the original IPv4 datagram on its way.

IPv4	1456 Bytes TCP + data

Example 4 shows what happens when the router acts in the role of a sending host with respect to PMTUD and in regards to the tunnel IPv4 packet.

This time the DF bit is set (DF = 1) in the original IPv4 header and the **tunnel path-mtu-discovery** command has been configured so that the DF bit is copied from the inner IPv4 header to the outer (GRE + IPv4) header.

Example 4

1. The forwarding router at the tunnel source receives a 1476-byte datagram with DF = 1 from the sending host.

IPv4	1456 bytes TCP + data

2. This router encapsulates the 1476-byte IPv4 datagram inside GRE to get a 1500-byte GRE IPv4 datagram.

This GRE IPv4 header has the DF bit set (DF = 1) since the original IPv4 datagram had the DF bit set.

This router then forwards this packet to the tunnel destination.

IPv4	GRE	IPv4	1456 bytes TCP

3. Again, assume there is a router between the tunnel source and destination with a link MTU of 1400.

This router does not fragment the tunnel packet because the DF bit is set (DF=1).

This router must drop the packet and send an ICMP error message to the tunnel source router, because that is the source IPv4 address on the packet.

IPv4	ICMP MTU 1400

4. The forwarding router at the tunnel source receives this "ICMP" error message and it lowers the GRE tunnel IPv4 MTU to 1376 (1400 - 24).

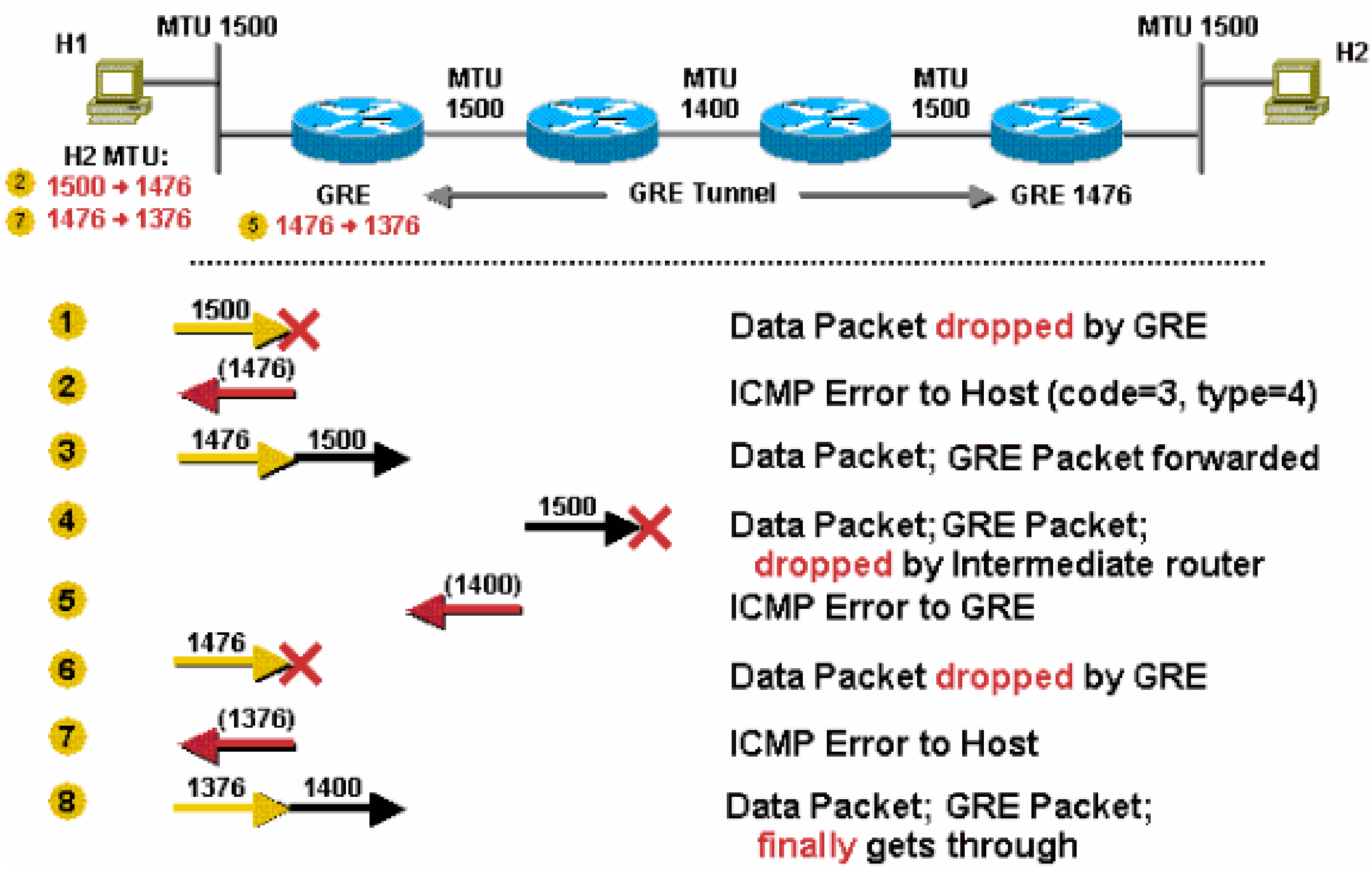
The next time the sending host retransmits the data in a 1476-byte IPv4 packet, this packet can be too large and this router then sends an "ICMP" error message to the sender with a MTU value of 1376.

When the sending host retransmits the data, it sends it in a 1376-byte IPv4 packet and this packet makes it through the GRE tunnel to the receiving host.

Example 5

This example illustrates GRE fragmentation. Fragment before encapsulation for GRE, then do PMTUD for the data packet, and the DF bit is not copied when the IPv4 packet is encapsulated by GRE.

The DF bit is not set. The GRE tunnel interface IPv4 MTU is, by default, 24 bytes less than the physical interface IPv4 MTU, so the GRE interface IPv4 MTU is 1476 as shown in the image.



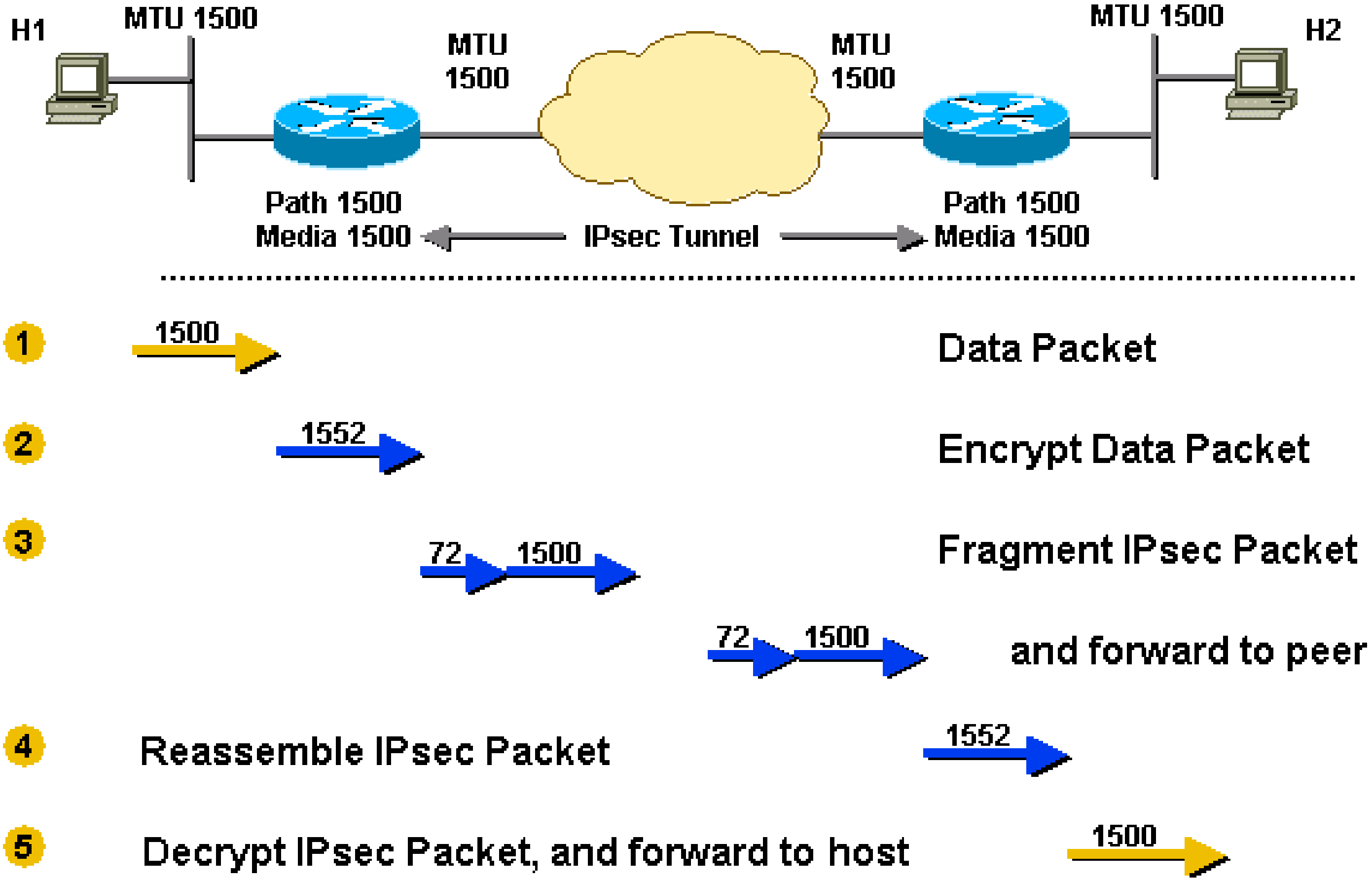
1. The sender sends a 1500-byte packet (20 byte IPv4 header + 1480 bytes of TCP payload).
2. Because the MTU of the GRE tunnel is 1476, the 1500-byte packet is broken into two IPv4 fragments of 1476 and 44 bytes, each in anticipation of the additional 24 byes of GRE header.
3. The 24 bytes of GRE header is added to each IPv4 fragment. Now the fragments are 1500 (1476 + 24) and 68 (44 + 24) bytes each.
4. The GRE + IPv4 packets that contain the two IPv4 fragments are forwarded to the GRE tunnel peer router.
5. The GRE tunnel peer router removes the GRE headers from the two packets.
6. This router forwards the two packets to the destination host.
7. The destination host reassembles the IPv4 fragments back into the original IPv4 datagram.

Example 6

This example is similar to Example 5, but this time the DF bit is set. The router is configured to do PMTUD on GRE + IPv4 tunnel packets with the **tunnel path-mtu-discovery**command, and the DF bit is copied from the original IPv4 header to the GRE IPv4 header.

If the router receives an ICMP error for the GRE + IPv4 packet, it reduces the IPv4 MTU on the GRE tunnel interface.

The GRE Tunnel IPv4 MTU is set to 24 bytes less than the physical interface MTU by default, so the GRE IPv4 MTU here is 1476. There is a 1400 MTU link in the GRE tunnel path as shown in the image.



1. The router receives a 1500-byte packet (20 byte IPv4 header + 1480 TCP payload), and it drops the packet. The router drops the packet because it is larger than the IPv4 MTU (1476) on the GRE tunnel interface.
2. The router sends an ICMP error to the sender telling it that the next-hop MTU is 1476. The host records this information, usually as a host route for the destination in its routing table.
3. The sending host uses a 1476-byte packet size when it resends the data. The GRE router adds 24 bytes of GRE encapsulation and ships out a 1500-byte packet.
4. The 1500-byte packet cannot traverse the 1400-byte link, so it is dropped by the intermediate router.
5. The intermediate router sends an ICMP (type = 3, code = 4) to the GRE router with a next-hop MTU of 1400. The GRE router reduces this to 1376 (1400 - 24) and sets an internal IPv4 MTU value on the GRE interface. This change can only be seen when you use the **debug tunnel** command; it cannot be seen in the output from the **show ip interface tunnel<#>** command.
6. The next time the host resends the 1476-byte packet, the GRE router drops the packet, since it is larger than the current IPv4 MTU (1376) on the GRE tunnel interface.
7. The GRE router sends another ICMP (type = 3, code = 4) to the sender with a next-hop MTU of 1376 and the host updates its current information with new value.
8. The host again resends the data, but now in a smaller 1376-byte packet, GRE adds 24 bytes of encapsulation and forward it on. This time the packet makes it to the GRE tunnel peer, where the packet is decapsulated and sent to the destination host.

Note: If the **tunnel path-mtu-discovery** command was not configured on the forwarding router in this scenario, and the DF bit was set in the packets forwarded through the GRE tunnel, Host 1 still succeeds in sending TCP/IPv4 packets to Host 2, but they get fragmented in the middle at the 1400 MTU link. Also the GRE tunnel peer has to reassemble them before it could decapsulate and forward them on.

Pure IPsec Tunnel Mode

The IPv4 Security (IPv4sec) Protocol is a standards-based method that provides privacy, integrity, and authenticity to information transferred across IPv4 networks.

IPv4sec provides IPv4 network-layer encryption. IPv4sec lengthens the IPv4 packet by adding at least one IPv4 header (tunnel mode).

The added header(s) varies in length dependent on the IPv4sec configuration mode but they do not exceed ~58 bytes (Encapsulating Security Payload (ESP) and ESP authentication (ESPauth)) per packet.

IPv4sec has two modes, tunnel mode and transport mode.

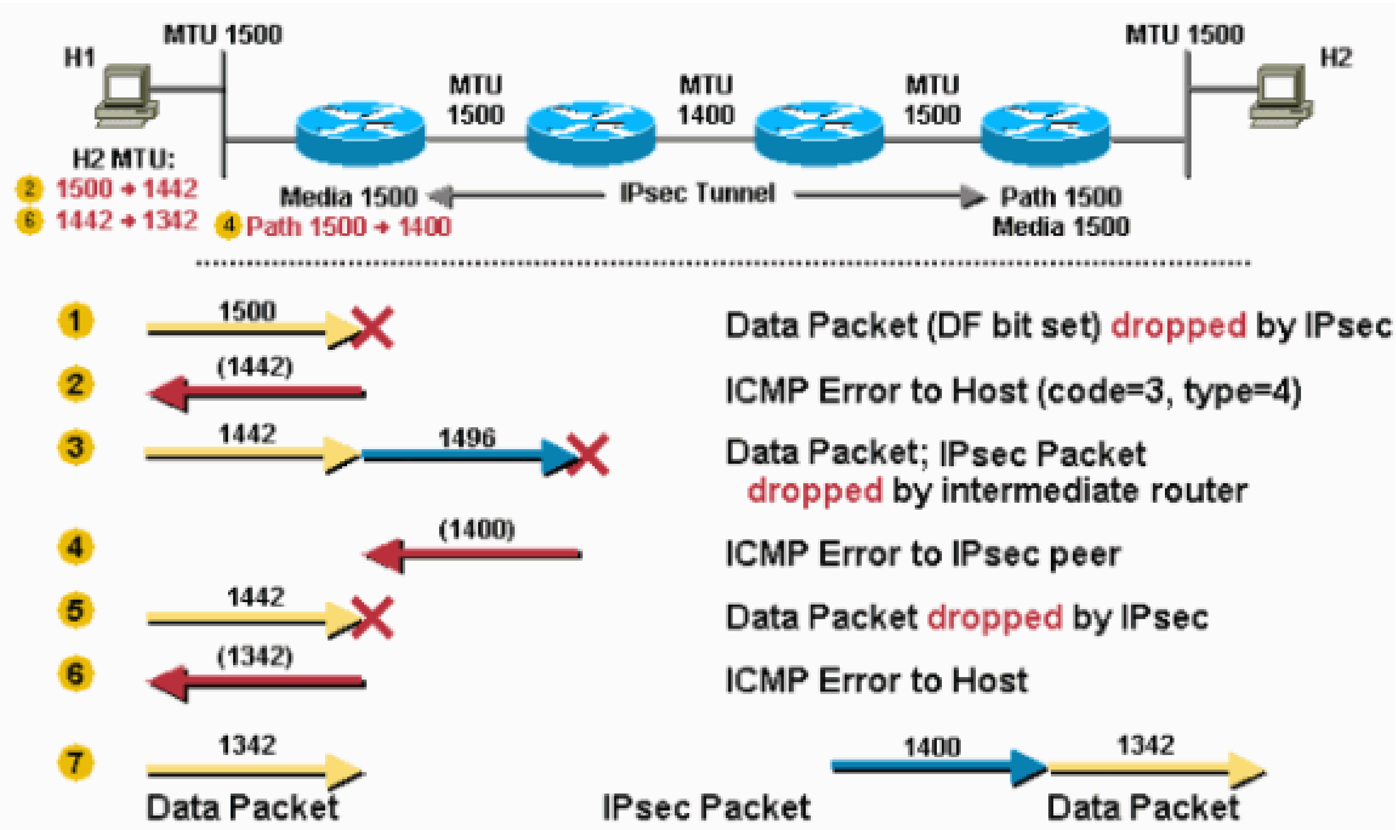
1. Tunnel mode is the default mode. With tunnel mode, the entire original IPv4 packet is protected (encrypted, authenticated, or both) and encapsulated by the IPv4sec headers and trailers. Then a new IPv4 header is prepended to the packet, which specifies the IPv4sec endpoints (peers) as the source and destination. Tunnel mode can be used with any unicast IPv4 traffic and must be used if IPv4sec protects traffic from hosts behind the IPv4sec peers. For example, tunnel mode is used with Virtual Private Networks (VPNs) where hosts on one protected network send packets to hosts on a different protected network via a pair of IPv4sec peers. With VPNs, the IPv4sec "tunnel" protects the IPv4 traffic between hosts by encrypting this traffic between the IPv4sec peer routers.
2. With transport mode (configured with the subcommand, **mode transport**, on the transform definition), only the payload of the original IPv4 packet is protected (encrypted, authenticated, or both). The payload is encapsulated by the IPv4sec headers and trailers. The original IPv4 headers remain intact, except that the IPv4 protocol field is changed to be ESP (50), and the original protocol value is saved in the IPv4sec trailer to be restored when the packet is decrypted. Transport mode is used only when the IPv4 traffic to be protected is between the IPv4sec peers themselves, the source and destination IPv4 addresses on the packet are the same as the IPv4sec peer addresses. Normally IPv4sec transport mode is only used when another tunneling protocol (like GRE) is used to first encapsulate the IPv4 data packet, then IPv4sec is used to protect the GRE tunnel packets.

IPv4sec always does PMTUD for data packets and for its own packets. There are IPv4sec configuration commands to modify PMTUD processing for the IPv4sec IPv4 packet, IPv4sec can clear, set, or copy the DF bit from the data packet IPv4 header to the IPv4sec IPv4 header. This is called the "DF Bit Override Functionality" feature.

> **Note**: Avoid fragmentation after encapsulation when hardware encryption with IPv4sec is done. Hardware encryption gives you throughput of about 50 Mbs which depends on the hardware, but if the IPv4sec packet is fragmented you loose 50 to 90 percent of the throughput. This loss is because the fragmented IPv4sec packets are process-switched for reassembly and then handed to the Hardware encryption engine for decryption. This loss of throughput can bring hardware encryption throughput down to the performance level of software encryption (2-10 Mbs).

Example 7

This scenario depicts IPv4sec fragmentation in action. In this scenario, the MTU along the entire path is 1500. In this scenario, the DF bit is not set.



1. The router receives a 1500-byte packet (20-byte IPv4 header + 1480 bytes TCP payload) destined for Host 2.
2. The 1500-byte packet is encrypted by IPv4sec and 52 bytes of overhead are added (IPv4sec header, trailer, and additional IPv4 header). Now IPv4sec needs to send a 1552-byte packet. Since the outbound MTU is 1500, this packet has to be fragmented.
3. Two fragments are created out of the IPv4sec packet. During fragmentation, an additional 20-byte IPv4 header is added for the second fragment, that result in a 1500-byte fragment and a 72-byte IPv4 fragment.
4. The IPv4sec tunnel peer router receives the fragments, strips off the additional IPv4 header and coalesces the IPv4 fragments back into the original IPv4sec packet. Then IPv4sec decrypts this packet.
5. The router then forwards the original 1500-byte data packet to Host 2.

Example 8

This example is similar to Example 6 except that in this case the DF bit is set in the original data packet and there is a link in the path between the IPv4sec tunnel peers that has a lower MTU than the other links.

This example demonstrates how the IPv4sec peer router performs both PMTUD roles, as described in the The Router as a PMTUD Participant at the Endpoint of a Tunnel section.

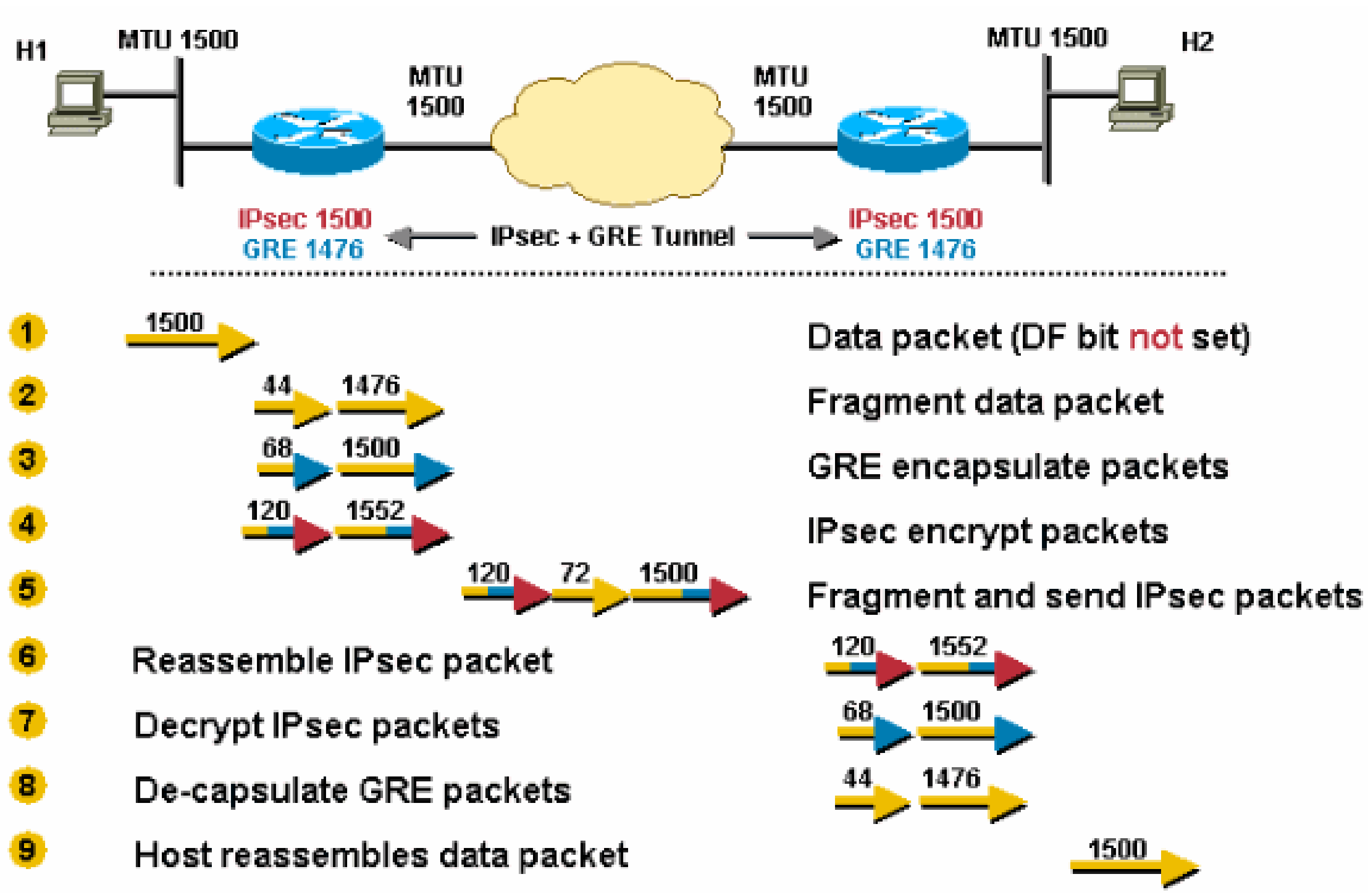
The IPv4sec PMTU changes to a lower value as the result of the need for fragmentation.

The DF bit is copied from the inner IPv4 header to the outer IPv4 header when IPv4sec encrypts a packet.

The media MTU and PMTU values are stored in the IPv4sec Security Association (SA).

The media MTU is based on the MTU of the outbound router interface and the PMTU is based on the minimum MTU seen on the path between the IPv4sec peers.

IPv4sec encapsulates/encrypts the packet before it attempts to fragment it as shown in the image.



1. The router receives a 1500-byte packet and drops it because the IPv4sec overhead, when added, makes the packet larger than the PMTU (1500).
2. The router sends an ICMP message to Host 1 telling it that the next-hop MTU is 1442 (1500 - 58 = 1442). This 58 bytes is the maximum IPv4sec overhead when you use IPv4sec ESP and ESPauth. The real IPv4sec overhead is possibly 7 bytes less than this value. Host 1 records this information, usually as a host route for the destination (Host 2), in its routing table.
3. Host 1 lowers its PMTU for Host 2 to 1442, so Host 1 sends smaller (1442 byte) packets when it retransmits the data to Host 2. The router receives the 1442-byte packet and IPv4sec adds 52 bytes of encryption overhead so the resulting IPv4sec packet is 1496 bytes. Because this packet has the DF bit set in its header it gets dropped by the middle router with the 1400-byte MTU link.
4. The middle router that dropped the packet sends an ICMP message to the sender of the IPv4sec packet (the first router) telling it that the next-hop MTU is 1400 bytes. This value is recorded in the IPv4sec SA PMTU.
5. The next time Host 1 retransmits the 1442-byte packet (it did not receive an acknowledgment for it), the IPv4sec drops the packet. The router drops the packet because the IPv4sec overhead, when added to the packet, makes it larger than the PMTU (1400).
6. The router sends an ICMP message to Host 1 telling it that the next-hop MTU is now 1342. (1400 - 58 = 1342). Host 1 records this information again.
7. When Host 1 again retransmits the data, it uses the smaller size packet (1342). This packet does not require fragmentation and makes it through the IPv4sec tunnel to Host 2.

GRE and IPv4sec Together

More complex interactions for fragmentation and PMTUD occur when IPv4sec is used in order to encrypt GRE tunnels.

IPv4sec and GRE are combined in this manner because IPv4sec does not support IPv4 multicast packets, which means that you cannot run a dynamic routing protocol over the IPv4sec VPN Network.

GRE tunnels do support multicast, so a GRE tunnel can be used to first encapsulate the dynamic routing protocol multicast packet in a GRE IPv4 unicast packet that can then be encrypted by IPv4sec.

When you do this, IPv4sec is often deployed in transport mode on top of GRE because the IPv4sec peers and the GRE tunnel endpoints (the routers) are the same, and transport-mode saves 20 bytes of IPv4sec overhead.

One interesting case is when an IPv4 packet has been split into two fragments and encapsulated by GRE.

In this case IPv4sec sees two independent GRE + IPv4 packets. Often in a default configuration one of these packets is large enough that it needs to be fragmented after it has been encrypted.

The IPv4sec peer has to reassemble this packet before decryption. This "double fragmentation" (once before GRE and again after IPv4sec) on the sending router increases latency and lowers throughput.

Reassembly is process-switched, so there is a CPU hit on the receiving router whenever this happens.

This situation can be avoided by setting the "ip mtu" on the GRE tunnel interface low enough to take into account the overhead from both GRE and IPv4sec (by default the GRE tunnel interface "ip mtu" is set to the outgoing real interface MTU - GRE overhead bytes).

This table lists the suggested MTU values for each tunnel/mode combination that assume the outgoing physical interface has an MTU of 1500.

Tunnel Combination	Specific MTU Needed	Recommended MTU
GRE + IPv4sec (Transport mode)	1440 bytes	1400 bytes
GRE + IPv4sec (Tunnel mode)	1420 bytes	1400 bytes

> **Note**: The MTU value of 1400 is recommended because it covers the most common GRE + IPv4sec mode combinations. Also, there is no discernable downside to allowing for an extra 20 or 40 bytes overhead. It is easier to remember and set one value and this value covers almost all scenarios.

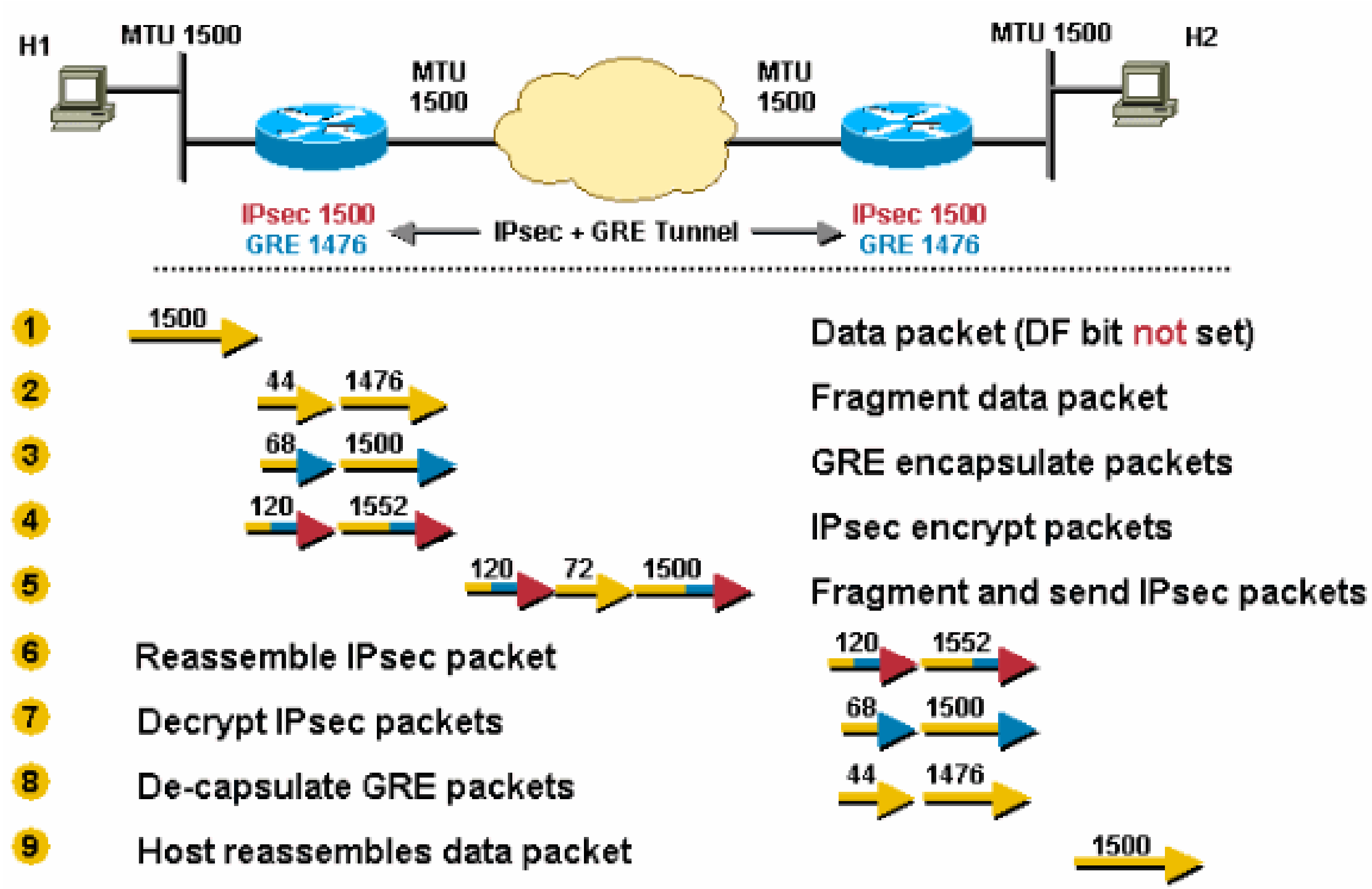
Example 9

IPv4sec is deployed on top of GRE. The outgoing physical MTU is 1500, the IPv4sec PMTU is 1500, and the GRE IPv4 MTU is 1476 (1500 - 24 = 1476).

TCP/IPv4 packets are therefore fragmented twice, once before GRE and once after IPv4sec.

The packet is fragmented before GRE encapsulation and one of these GRE packets are fragmented again after IPv4sec encryption.

Configuring "ip mtu 1440" (IPv4sec Transport mode) or "ip mtu 1420" (IPv4sec Tunnel mode) on the GRE tunnel would remove the possibility of double fragmentation in this scenario.

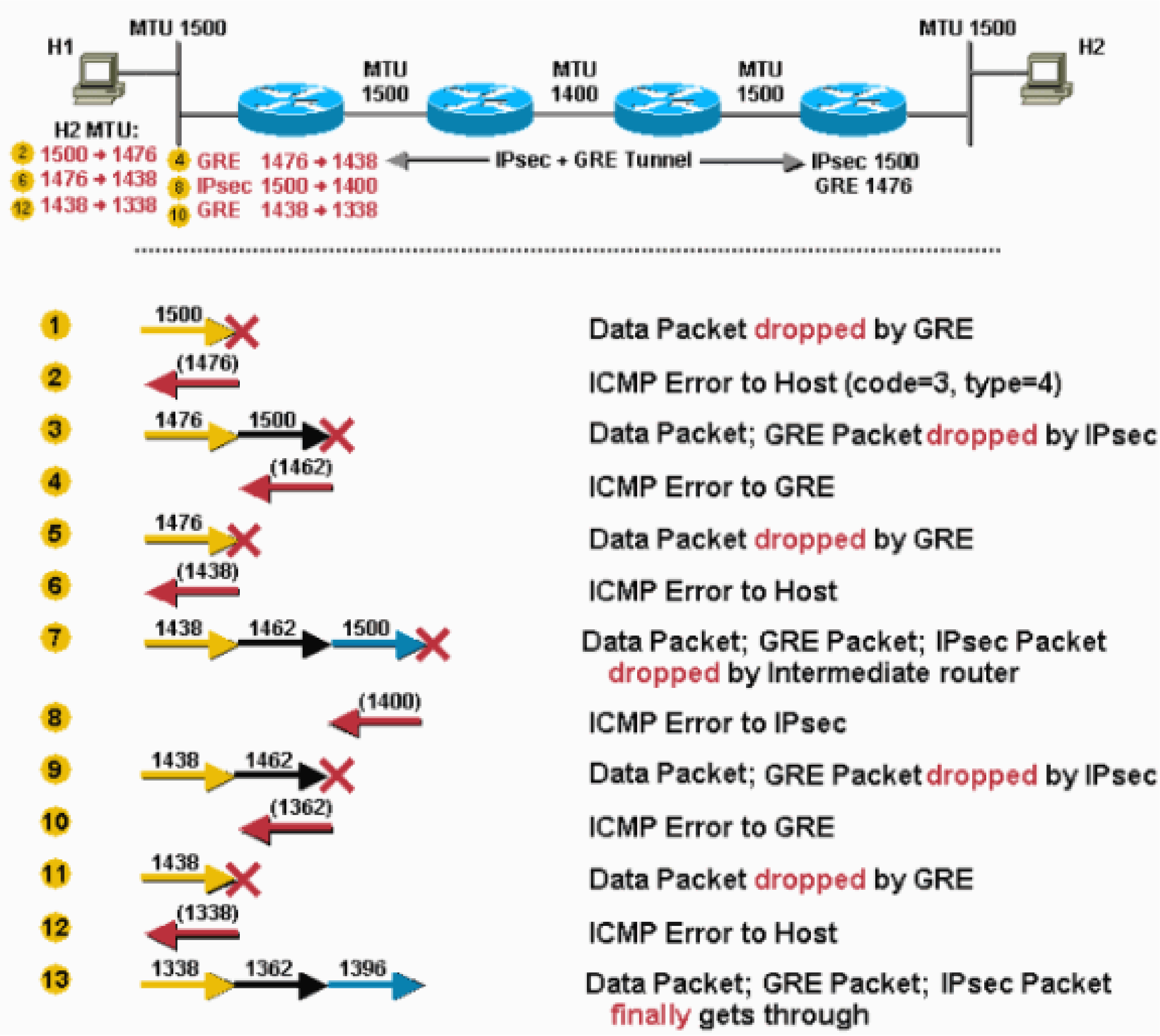


1. The router receives a 1500-byte datagram.
2. Before encapsulation, GRE fragments the 1500-byte packet into two pieces, 1476 (1500 - 24 = 1476) and 44 (24 data + 20 IPv4 header) bytes.
3. GRE encapsulates the IPv4 fragments, which adds 24 bytes to each packet. This results in two GRE + IPv4sec packets of 1500 (1476 + 24 = 1500) and 68 (44 + 24) bytes each.
4. IPv4sec encrypts the two packets, that add 52 byes (IPv4sec tunnel-mode) of encapsulation overhead to each, in order to give a 1552-byte and a 120-byte packet.
5. The 1552-byte IPv4sec packet is fragmented by the router because it is larger than the outbound MTU (1500). The 1552-byte packet is split into pieces, a 1500-byte packet and a 72-byte packet (52 bytes "payload" plus an additional 20-byte IPv4 header for the second fragment). The three packets 1500-byte, 72-byte, and 120-byte packets are forwarded to the IPv4sec + GRE peer.
6. The receiving router reassembles the two IPv4sec fragments (1500 bytes and 72 bytes) in order to get the original 1552-byte IPv4sec + GRE packet. Nothing needs to be done to the 120-byte IPv4sec + GRE packet.
7. IPv4sec decrypts both 1552-byte and 120-byte IPv4sec + GRE packets in order to get 1500-byte and 68-byte GRE packets.
8. GRE decapsulates the 1500-byte and 68-byte GRE packets in order to get 1476-byte and 44-byte IPv4 packet fragments. These IPv4 packet fragments are forwarded to the destination host.
9. Host 2 reassembles these IPv4 fragments in order to get the original 1500-byte IPv4 datagram.

Scenario 10 is similar to Scenario 8 except there is a lower MTU link in the tunnel path. This is a worst case scenario for the first packet sent from Host 1 to Host 2. After the last step in this scenario, Host 1 sets the correct PMTU for Host 2 and all is well for the TCP connections between Host 1 and Host 2. TCP flows between Host 1 and other hosts (reachable via the IPv4sec + GRE tunnel) only have to go through the last three steps of Scenario 10.

In this scenario, the **tunnel path-mtu-discovery** command is configured on the GRE tunnel and the DF bit is set on TCP/IPv4 packets that originate from Host 1.

Example 10



- The router receives a 1500-byte packet. This packet is dropped by GRE because GRE cannot fragment or forward the packet because the DF bit is set, and the packet size exceeds the outbound interface "ip mtu" after adding the GRE overhead (24 bytes).
- The router sends an ICMP message to Host 1 in order to let it know that the next-hop MTU is 1476 (1500 - 24 = 1476).
- Host 1 changes its PMTU for Host 2 to 1476 and sends the smaller size when it retransmits the packet. GRE encapsulates it and hands the 1500-byte packet to IPv4sec. IPv4sec drops the packet because GRE has copied the DF bit (set) from the inner IPv4 header, and with the IPv4sec overhead (maximum 38 bytes), the packet is too large to forward out the physical interface.
- IPv4sec sends an ICMP message to GRE which indicates that the next-hop MTU is 1462 bytes (since a maximum 38 bytes are added for encryption and IPv4 overhead). GRE records the value 1438 (1462 - 24) as the "ip mtu" on the tunnel interface.

- **Note**: This change in value is stored internally and cannot be seen in the output of the **show ip interface tunnel<#>**command. You only see this change if you turn use the **debug tunnel** command.

- The next time Host 1 retransmits the 1476-byte packet, GRE drops it.
- The router sends an ICMP message to Host 1 which indicates that 1438 is the next-hop MTU.
- Host 1 lowers the PMTU for Host 2 and retransmits a 1438-byte packet. This time, GRE accepts the packet, encapsulates it, and hands it off to IPv4sec for encryption.
- The IPv4sec packet is forwarded to the intermediate router and dropped because it has an outbound interface MTU of 1400.
- The intermediate router sends an ICMP message to IPv4sec which tells it that the next-hop MTU is 1400. This value is recorded by IPv4sec in the PMTU value of the associated IPv4sec SA.
- When Host 1 retransmits the 1438-byte packet, GRE encapsulates it and hands it to IPv4sec. IPv4sec drops the packet because it has changed its own PMTU to 1400.
- IPv4sec sends an ICMP error to GRE which indicates that the next-hop MTU is 1362, and GRE records the value 1338 internally.
- When Host 1 retransmits the original packet (because it did not receive an acknowledgment), GRE drops it.
- The router sends an ICMP message to Host 1 which indicates the next-hop MTU is 1338 (1362 - 24 bytes). Host 1 lowers its PMTU for Host 2 to 1338.
- Host 1 retransmits a 1338-byte packet and this time it can finally get all the way through to Host 2.

More Recommendations

Configuring the **tunnel path-mtu-discovery** command on a tunnel interface can help GRE and IPv4sec interaction when they are configured on the same router.

Without the **tunnel path-mtu-discovery** command configured, the DF bit would always be cleared in the GRE IPv4 header.

This allows the GRE IPv4 packet to be fragmented even though the encapsulated data IPv4 header had the DF bit set, which normally would not allow the packet to be fragmented.

If the **tunnel path-mtu-discovery** command is configured on the GRE tunnel interface:

1. GRE copies the DF bit from the data IPv4 header to the GRE IPv4 header.
2. If the DF bit is set in the GRE IPv4 header and the packet is "too large" after IPv4sec encryption for the IPv4 MTU on the physical outgoing interface, then IPv4sec drops the packet and notifies the GRE tunnel to reduce its IPv4 MTU size.
3. IPv4sec does PMTUD for its own packets and if the IPv4sec PMTU changes (if it is reduced), then IPv4sec does not immediately notify GRE, but when another larger packet comes through, then the process in step 2 occurs.
4. The GRE IPv4 MTU is now smaller, so it drops any data IPv4 packets with the DF bit set that are now too large and send an ICMP message to the sending host.

The **tunnel path-mtu-discovery** command helps the GRE interface set its IPv4 MTU dynamically, rather than statically with the **ip mtu** command. It is actually recommended that both commands are used.

The **ip mtu** command is used to provide room for the GRE and IPv4sec overhead relative to the local physical outgoing interface IPv4 MTU.

The **tunnel path-mtu-discovery** command allows the GRE tunnel IPv4 MTU to be further reduced if there is a lower IPv4 MTU link in the path between the IPv4sec peers.

Here are some of the things you can do if you have problems with PMTUD in a network where there are GRE + IPv4sec tunnels configured.

This list begins with the most desirable solution.

1. Fix the problem with PMTUD not working, which is usually caused by a router or firewall that blocks ICMP.
2. Use the **ip tcp adjust-mss** command on the tunnel interfaces so that the router reduces the TCP MSS value in the TCP SYN packet. This helps the two end hosts (the TCP sender and receiver) to use packets small enough so that PMTUD is not needed.
3. Use policy routing on the ingress interface of the router and configure a route map to clear the DF bit in the data IPv4 header before it gets to the GRE tunnel interface. This allows the data IPv4 packet to be fragmented before GRE encapsulation.
4. Increase the "ip mtu" on the GRE tunnel interface to be equal to the outbound interface MTU. This allows the data IPv4 packet to be GRE encapsulated without fragmenting it first. The GRE packet is then IPv4sec encrypted and then fragmented to go out the physical outbound interface. In this case you would not configure **tunnel path-mtu-discovery** command on the GRE tunnel interface. This can dramatically reduce the throughput because IPv4 packet reassembly on the IPv4sec peer is done in process-switching mode.

Related Information

- **IP Routing Support Page**
- **IPSec (IP Security Protocol) Support Page**
- **RFC 1191 Path MTU Discovery**
- **RFC 1063 IP MTU Discovery Options**
- **RFC 791 Internet Protocol**
- **RFC 793 Transmission Control Protocol**
- **RFC 879 The TCP Maximum Segment Size and Related Topics**
- **RFC 1701 Generic Routing Encapsulation (GRE)**
- **RFC 1241 A Scheme for an Internet Encapsulation Protocol**
- **RFC 2003 IP Encapsulation within IP**
- **Technical Support & Documentation - Cisco Systems**