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Processing of IPv6 "atomic" fragments
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Abstract

The IPv6 specification allows packets to contain a Fragment Header without the packet being actually fragmented into multiple pieces (we refer to these packets as "atomic fragments"). Such packets are typically sent by hosts that have received an ICMPv6 "Packet Too Big" error message that advertises a "Next-Hop MTU" smaller than 1280 bytes, and are currently processed by some implementations as normal "fragmented traffic" (i.e., they are "reassembled" with any other queued fragments that supposedly correspond to the same original packet). Thus, an attacker can cause hosts to employ "atomic fragments" by forging ICMPv6 "Packet Too Big" error messages, and then launch any fragmentation-based attacks against such traffic. This document discusses the generation of the aforementioned "atomic fragments" and the corresponding security implications. Additionally, this document formally updates [RFC 2460](#) and [RFC 5722](#) such that IPv6 atomic fragments are processed independently of any other fragments, thus completely eliminating the aforementioned attack vector.

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Internet-Draft

IPv6 atomic fragments

March 2013

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Table of Contents

1.	Introduction	3
2.	Terminology	5
3.	Generation of IPv6 'atomic fragments'	6
4.	Updating RFC 2460 and RFC 5722	8
5.	IANA Considerations	9
6.	Security Considerations	10
7.	Acknowledgements	11
8.	References	12
8.1.	Normative References	12
8.2.	Informative References	12
Appendix A.	Survey of processing of IPv6 atomic fragments by different operating systems	13
	Author's Address	14

1. Introduction

[RFC2460] specifies the IPv6 fragmentation mechanism, which allows IPv6 packets to be fragmented into smaller pieces such that they fit in the Path-MTU to the intended destination(s). [RFC2460] allowed fragments to overlap, thus leading to ambiguity in the result of the reassembly process, which could be leveraged by attackers to bypass firewall rules and/or evade Network Intrusion Detection Systems (NIDS) [RFC5722].

[RFC5722] forbid overlapping fragments, specifying that when overlapping fragments are detected, all the fragments corresponding to that packet must be silently discarded.

As specified in [Section 5 of \[RFC2460\]](#), when a host receives an ICMPv6 "Packet Too Big" message advertising a "Next-Hop MTU" smaller than 1280 (the minimum IPv6 MTU), it is not required to reduce the assumed Path-MTU, but must simply include a Fragment Header in all subsequent packets sent to that destination. The resulting packets will thus *not* be actually fragmented into several pieces, but just include a Fragment Header with both the "Fragment Offset" and the "M" flag set to 0 (we refer to these packets as "atomic fragments"). IPv6/IPv4 translators employ the Fragment Identification information found in the Fragment Header to select an appropriate Fragment Identification value for the resulting IPv4 fragments.

While these packets are really "atomic fragments" (they can be processed by the IPv6 module and handed to the upper-layer protocol without waiting for any other fragments), many IPv6 implementations process them as regular fragments. Namely, they try to perform IPv6 fragment reassembly with the "atomic fragment" and any other fragments already queued with the same set {IPv6 Source Address, IPv6 Destination Address, Fragment Identification}. For example, in the case of IPv6 implementations that have been updated to support [RFC5722], if a fragment with the same {IPv6 Source Address, IPv6 Destination Address, Fragment Identification} is already queued for

reassembly at a host when an "atomic fragment" is received with the same set {IPv6 Source Address, IPv6 Destination Address, Fragment Identification}, and both fragments overlap, all the fragments will be silently discarded.

Processing of IPv6 "atomic fragments" as regular fragmented packets clearly provides an unnecessary vector to perform fragmentation-based attacks against non-fragmented traffic (i.e., IPv6 datagrams that are not really split into multiple pieces, but that just include a Fragment Header).

IPv6 fragmentation attacks have been discussed in great detail in

Gont

Expires September 22, 2013

[Page 3]

Internet-Draft

IPv6 atomic fragments

March 2013

[I-D.gont-6man-predictable-fragment-id] and [[CPNI-IPv6](#)], and [[RFC5722](#)] describes a specific firewall-circumvention attack that could be performed by leveraging overlapping fragments. The possible IPv6 fragmentation-based attacks are, in most cases, "ports" of the IPv4 fragmentation attacks discussed in [[RFC6274](#)].

[Section 3](#) describes the generation of IPv6 "atomic fragments", and how they can be remotely "triggered" by a remote attacker. [Section 4](#) formally updates [[RFC2460](#)] and [[RFC5722](#)] such that the aforementioned attack vector is eliminated. [Appendix A](#) contains a survey of the generation and processing of IPv6 atomic fragments in different versions of a number of popular IPv6 implementations.

[2.](#) Terminology

IPv6 atomic fragments

IPv6 packets that contain a Fragment Header with the Fragment Offset set to 0 and the M flag set to 0.

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. Generation of IPv6 'atomic fragments'

[Section 5 of \[RFC2460\]](#) states:

In response to an IPv6 packet that is sent to an IPv4 destination (i.e., a packet that undergoes translation from IPv6 to IPv4), the originating IPv6 node may receive an ICMP Packet Too Big message reporting a Next-Hop MTU less than 1280. In that case, the IPv6 node is not required to reduce the size of subsequent packets to less than 1280, but must include a Fragment header in those packets so that the IPv6-to-IPv4 translating router can obtain a suitable Identification value to use in resulting IPv4 fragments. Note that this means the payload may have to be reduced to 1232 octets (1280 minus 40 for the IPv6 header and 8 for the Fragment header), and smaller still if additional extension headers are

used.

This means that any ICMPv6 "Packet Too Big" message advertising a "Next-Hop MTU" smaller than 1280 could trigger the generation of the so-called "atomic fragments" (i.e., IPv6 datagrams that include a Fragment Header, but that are composed of a single fragment, with both the "Fragment Offset" and the "M" fields of the Fragment Header set to 0). This can be leveraged to perform a variety of fragmentation-based attacks [[I-D.gont-6man-predictable-fragment-id](#)] [[CPNI-IPv6](#)].

For example, an attacker could forge IPv6 fragments with an appropriate {IPv6 Source Address, IPv6 Destination Address, Fragment Identification} tuple, such that these malicious fragments are incorrectly "reassembled" by the destination host together with some of the legitimate fragments of the original packet, thus leading to packet drops (and a potential Denial of Service).

From a security standpoint, this situation is exacerbated by the following factors:

- o Many implementations fail to perform validation checks on the received ICMPv6 error messages, as recommended in [Section 5.2 of \[RFC4443\]](#) and documented in [[RFC5927](#)]. It should be noted that in some cases, such as when an ICMPv6 error message has (supposedly) been elicited by a connection-less transport protocol (or some other connection-less protocol being encapsulated in IPv6), it may be virtually impossible to perform validation checks on the received ICMPv6 error messages.
- o Upon receipt of one of the aforementioned ICMPv6 "Packet Too Big" error messages, the Destination Cache [[RFC4861](#)] is usually updated

to reflect that any subsequent packets to such destination should include a Fragment Header. This means that a single ICMPv6 "Packet Too Big" error message might affect multiple communication instances (e.g., TCP connections) with such destination.

- o Some implementations employ predictable Fragment Identification values, thus greatly improving the chances of an attacker of successfully performing fragmentation-based attacks

[[I-D.gont-6man-predictable-fragment-id](#)].

Gont

Expires September 22, 2013

[Page 7]

Internet-Draft

IPv6 atomic fragments

March 2013

4. Updating [RFC 2460](#) and [RFC 5722](#)

[Section 4.5 of \[RFC2460\]](#) and [Section 4 of \[RFC5722\]](#) are updated as follows:

A host that receives an IPv6 packet which includes a Fragment Header with the "Fragment Offset" equal to 0 and the "M" flag equal to 0 MUST process such packet in isolation from any other packets/fragments, even if such packets/fragments contain the same set {IPv6 Source Address, IPv6 Destination Address, Fragment Identification}. A received "atomic fragments" should be "reassembled" from the contents of that sole fragment.

The Unfragmentable Part of the reassembled packet consists of all headers up to, but not including, the Fragment header of the received atomic fragment.

The Next Header field of the last header of the Unfragmentable Part of the reassembled packet is obtained from the Next Header field of the Fragment header of the received atomic fragment.

The Payload Length of the reassembled packet is obtained by subtracting the length of the Fragment Header (that is, 8) from the Payload Length of the received atomic fragment.

Additionally, if any fragments with the same set {IPv6 Source Address, IPv6 Destination Address, Fragment Identification} are present in the fragment reassembly queue when the atomic fragment is received, such fragments MUST NOT be discarded upon receipt of the "colliding" IPv6 atomic fragment, since IPv6 atomic fragments MUST NOT interfere with "normal" fragmented traffic.

[5.](#) IANA Considerations

There are no IANA registries within this document. The RFC-Editor can remove this section before publication of this document as an RFC.

6. Security Considerations

This document describes how the traditional processing of IPv6 atomic fragments enables the exploitation of fragmentation-based attacks (such as those described in [[I-D.gont-6man-predictable-fragment-id](#)] and [[CPNI-IPv6](#)]). This document formally updates [[RFC2460](#)] and [[RFC5722](#)], such that IPv6 atomic fragments are processed independently of any other fragments, thus completely eliminating the aforementioned attack vector.

7. Acknowledgements

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Fernando Gont would like to thank CPNI (<http://www.cpni.gov.uk>) for their continued support.

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[CPNI-IPv6]

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[I-D.gont-6man-predictable-fragment-id]

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Gont

Expires September 22, 2013

[Page 12]

Internet-Draft

IPv6 atomic fragments

March 2013

[Appendix A](#). Survey of processing of IPv6 atomic fragments by different operating systems

This section includes a survey of the support of IPv6 atomic fragments in popular operating systems, as tested in October 30, 2012.

Operating System	Generates atomic fragments	Implements this specification
FreeBSD 8.0	No	No
FreeBSD 8.2	Yes	No
FreeBSD 9.0	Yes	No
Linux 3.0.0-15	Yes	Yes

NetBSD 5.1	No	No
NetBSD-current	No	Yes
OpenBSD-current	Yes	Yes
Solaris 11	Yes	Yes
Windows XP SP2	Yes	No
Windows Vista (Build 6000)	Yes	No
Windows 7 Home Premium	Yes	No

Table 1: Processing of IPv6 atomic fragments by different OSes

In the table above, "generates atomic fragments" notes whether an implementation generates atomic fragments in response to received ICMPv6 Packet Too Big error messages that advertise a MTU smaller than 1280 bytes.

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