

Network Working Group
Internet-Draft
Intended status: Informational
Expires: April 05, 2014

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October 02, 2013

LISP Threats Analysis
draft-ietf-lisp-threats-06.txt

Abstract

This document discusses potential security concerns with the Locator/Identifier Separation Protocol (LISP) if deployed in the Internet and proposes a set of recommendations to mitigate the identified threats and to reach a level of security equivalent to what is observed in the Internet today (i.e., without LISP). By following the recommendations of this draft a LISP deployment can achieve a security level that is comparable to the existing Internet architecture.

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1. Introduction

The Locator/ID Separation Protocol (LISP) is defined in [\[RFC6830\]](#). The present document assesses the security level and identifies

security threats in the LISP specification if LISP is deployed in the Internet (i.e., a public non-trustable environment). As a result of the performed analysis, the document discusses the severity of the threats and proposes recommendations to reach the same level of security in LISP than in Internet today (e.g., without LISP).

The document is composed of three main parts: the first discussing the LISP data-plane; while the second discussing the LISP control-plane. The final part summarizes the recommendations to prevent the identified threats.

The LISP data-plane consists of LISP packet encapsulation, decapsulation, and forwarding and includes the EID-to-RLOC Cache and EID-to-RLOC Database data structures used to perform these operations.

The LISP control-plane consists in the mapping distribution system, which can be one of the mapping distribution systems proposed so far (e.g., [[RFC6830](#)], [[I-D.ietf-lisp-ddt](#)], [[RFC6836](#)], [[RFC6833](#)], [[I-D.meyer-lisp-cons](#)], and [[RFC6837](#)]), and the Map-Request, Map-Reply, Map-Register, and Map-Notification messages.

This document does not consider all the possible uses of LISP as discussed in [[RFC6830](#)]. The document focuses on LISP unicast, including as well LISP Interworking [[RFC6832](#)], LISP-MS [[RFC6833](#)], LISP Map-Versioning [[RFC6834](#)], and briefly considering the ALT mapping system described in [[RFC6836](#)] and the Delegated Database Tree mapping system described in [[I-D.ietf-lisp-ddt](#)]. The reading of these documents is a prerequisite for understanding the present document.

Unless otherwise stated, the document assumes a generic IP service and does not discuss the difference, from a security viewpoint, between using IPv4 or IPv6.

This document has identified several threats on LISP in the case of public deployments. However, most of the threats can be prevented with careful deployment and configuration and general rules in security that consist in activating only features that are necessary in the deployment and to carefully verifying the validity of the information obtained from third parties also applies in the case of LISP. Finally, this document has not identified any threats that would require a change in the LISP protocol or architecture.

[2.](#) Definition of Terms

The present document does not introduce any other new term, compared to the main LISP specification. For a complete list of terms please refer to [\[RFC6830\]](#).

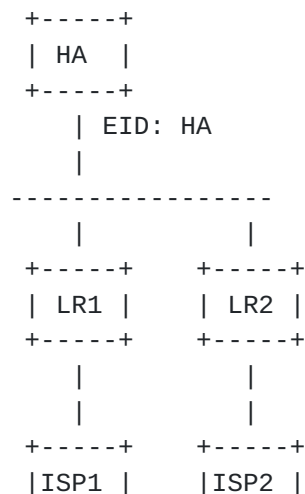
3. On-path Attackers

On-path attackers are attackers that are able to capture and modify all the packets exchanged between an Ingress Tunnel Router (ITR) and an Egress Tunnel Router (ETR). To cope with such an attacker, cryptographic techniques such as those used by IPSec ([\[RFC4301\]](#)) are required. As with IP, LISP relies on higher layer cryptography to secure packet payloads from on path attacks, so we do not consider on-path attackers in this document.

Similarly, a time-shifted attack is an attack where the attacker is temporarily on the path between two communicating hosts. While it is on-path, the attacker sends specially crafted packets or modifies packets exchanged by the communicating hosts in order to disturb the packet flow (e.g., by performing a man in the middle attack). An important issue for time-shifted attacks is the duration of the attack once the attacker has left the path between the two communicating hosts. We do not consider time-shifted attacks in this document.

4. Off-Path Attackers: Reference Environment

Throughout this document we consider the reference environment shown in the figure below. There are two hosts attached to LISP routers: HA and HB. HA is attached to the two LISP xTRs LR1 and LR2, which in turn are attached to two different ISPs. HB is attached to the two LISP xTRs LR3 and LR4. HA and HB are the EIDs of the two hosts. LR1, LR2, LR3, and LR4 are the RLOCs of the xTRs. PxTR is a proxy xTR and MR/MS plays the roles of Map Server and/or Map Resolver.



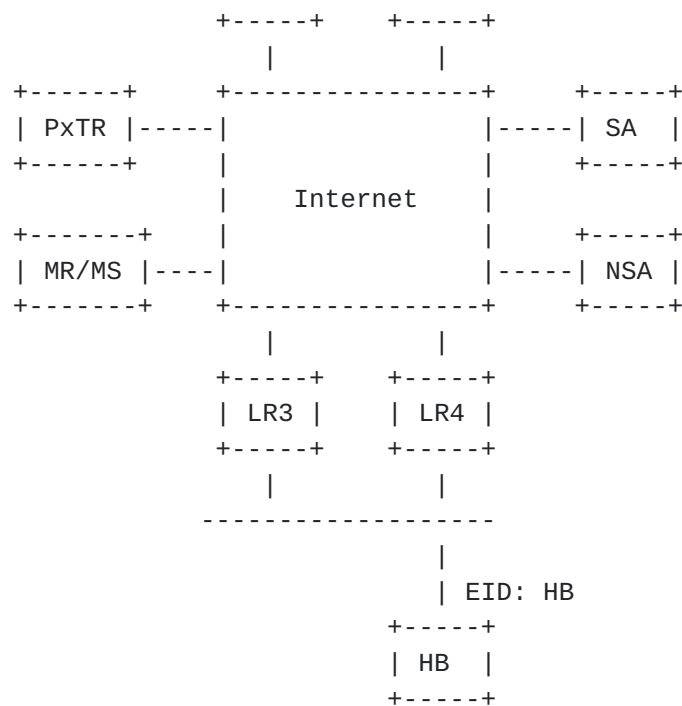


Figure 1: Reference Network

We consider two off-path attackers with different capabilities:

SA is an off-path attacker that is able to send spoofed packets, i.e., packets with a different source IP address than its assigned IP address. SA stands for Spoofing Attacker.

NSA is an off-path attacker that is only able to send packets whose source address is its assigned IP address. NSA stands for Non Spoofing Attacker.

It should be noted that with LISP, packet spoofing is slightly different than in the current Internet. Generally the term "spoofed packet" indicates a packet containing a source IP address that is not the one of the actual originator of the packet. Since LISP uses encapsulation, the spoofed address could be in the outer header as well as in the inner header, this translates in two types of spoofing:

EID Spoofing: the originator of the packet puts in it a spoofed EID. The packet will be normally encapsulated by the ITR of the site (or a PITR if the source site is not LISP enabled).

RLOC Spoofing: the originator of the packet generates directly a LISP-encapsulated packet with a spoofed source RLOC.

Note that the two types of spoofing are not mutually exclusive, rather all combinations are possible and could be used to perform different kind of attacks.

In the reference environment, both SA and NSA attackers are capable of sending LISP encapsulated data packets and LISP control packets. This means that SA is able to perform both RLOC and EID spoofing while NSA can only perform EID spoofing. They may also send other types of IP packets such as ICMP messages. We assume that both attackers can query the LISP mapping system (e.g., through a public Map Resolver) to obtain the mappings for both HA and HB.

5. Attack vectors

This section presents techniques that can be used by attackers to succeed attacks leveraging the LISP protocol and architecture. This section focuses on the techniques while [Section 6](#) presents the attacks that can be succeeded while using these techniques.

5.1. EID-to-RLOC Database

The EID-to-RLOC Database on each xTR maintains the set of mappings related to the EID-Prefixes that are "behind" the xTR. Where "behind" means that at least one of the xTR's globally visible IP addresses is a RLOC for those EID-Prefixes.

As described in [[RFC6830](#)], the EID-to-RLOC Database content is determined by configuration. This means that the only way to attack this data structure is by gaining privileged access to the xTR. As such, it is out of the scope of LISP to propose any mechanism to protect routers and, hence, it is no further analyzed in this document.

5.2. EID-to-RLOC Cache

The EID-to-RLOC Cache (also called the Map-Cache) is the data structure that stores a copy of the mappings retrieved from a remote ETR's mapping database via the LISP control-plane. Attacks against this data structure could happen either when the mappings are first installed in the cache or by corrupting (poisoning) the mappings already present in the cache.

In this document we call "cache poisoning attack", any attack that alters the EID-to-RLOC Cache. Cache poisoning attacks are used to alter (any combination of) the following parts of mapping installed in the EID-to-RLOC Cache:

- o EID prefix

- o RLOC list
- o RLOC priority
- o RLOC weight
- o RLOC reachability
- o Mapping TTL
- o Mapping version
- o Mapping Instance ID

5.3. Attack using the data-plane

The data-plane is constituted of the operations of encapsulation, decapsulation, and forwarding as well as the content of the EID-to-RLOC Cache and EID-to-RLOC Database as specified in the original LISP document ([[RFC6830](#)]).

5.3.1. Attacks not leveraging on the LISP header

An attacker can inject packets into flows without using the LISP header, i.e., with the N, L, E, V, and I bits ([[RFC6830](#)]).

To inject a packet in the HA-HB flow, a spoofing off-path attacker (SA) could send a LISP encapsulated packet whose source is set to LR1 or LR2 and destination LR3 or LR4. The packet will reach HB as if the packet was sent by host HA. This is not different from today's Internet where a spoofing off-path attacker may inject data packets in any flow. A non-spoofing off-path attacker (NSA) could only send a packet whose source address is set to its assigned IP address. The destination address of the encapsulated packet could be LR3 or LR4.

5.3.1.1. Gleaning Attacks

In order to reduce the time required to obtain a mapping, [[RFC6830](#)] proposes the gleaning mechanism that allows an ITR to learn a mapping from the LISP data encapsulated packets and the Map-Request packets that it receives. LISP data encapsulated packet contains a source RLOC, destination RLOC, source EID and destination EID. When an ITR receives a data encapsulated packet coming from a source EID for which it does not already know a mapping, it may insert the mapping between the source RLOC and the source EID in its EID-to-RLOC Cache. Gleaning could also be used when an ITR receives a Map-Request as the Map-Request also contains a source EID address and a source RLOC. Once a gleaned entry has been added to the EID-to-RLOC cache, the

LISP ITR sends a Map-Request to retrieve the mapping for the gleaned EID from the mapping system. [RFC6830] recommends storing the gleaned entries for only a few seconds.

An attacker can send LISP encapsulated packets to host HB with host HA's EID and if the xTRs that serve host HB do not store a mapping for host HA at that time The xTR will store the gleaned entry and use it to return the packets sent by host HB. In parallel, the ETR will send a Map-Request to retrieve the mapping for HA but until the reception of the Map-Reply, host HB will exchange packets with the attacker instead of HA.

Similarly, if an off-path attacker knows that hosts HA and HB that resides in different sites will exchange information at time t the attacker could send to LR1 (resp. LR3) a LISP data encapsulated packet whose source RLOC is its IP address and contains an IP packet whose source is set to HB (resp. HA). The attacker chooses a packet that will not trigger an answer, for example the last part of a fragmented packet. Upon reception of these packets, LR1 and LR3 install gleaned entries that point to the attacker. If host HA is willing to establishes a flow with host HB at that time, the packets that they exchange will pass through the attacker as long as the gleaned entry is active on the xTRs.

By itself, an attack made solely using gleaning cannot last long, however it should be noted that with current network capacities, a large amount of packets might be exchanged during even a small fraction of time.

5.3.1.2. Threats concerning Interworking

[RFC6832] defines Proxy-ITR And Proxy-ETR network elements to allow LISP and non-LISP sites to communicate. The Proxy-ITR has functionality similar to the ITR, however, its main purpose is to encapsulate packets arriving from the DFZ in order to reach LISP sites. A Proxy-ETR has functionality similar to the ETR, however, its main purpose is to inject de-encapsulated packets in the DFZ in order to reach non-LISP Sites from LISP sites. As a PITR (resp. PETR) is a particular case of ITR (resp. ETR), it is subject to same attacks than ITRs (resp. ETR).

PxTRs can be targeted by attacks aiming to influence traffic between LISP and non-LISP sites but also to launch relay attacks.

It is worth to notice that when PITR and PETR functions are separated, attacks targeting xTRs are ineffective.

5.3.2. Attacks leveraging on the LISP header

The main LISP document [[RFC6830](#)] defines several flags that modify the interpretation of the LISP header in data packets. In this section, we discuss how an off-path attacker could exploit this LISP header.

5.3.2.1. Attacks using the Locator Status Bits

When the L bit is set to 1, it indicates that the second 32-bits longword of the LISP header contains the Locator Status Bits. In this field, each bit position reflects the status of one of the RLOCs mapped to the source EID found in the encapsulated packet. In particular, a packet with the L bit set and all Locator Status Bits set to zero indicates that none of the locators of the encapsulated source EID are reachable. The reaction of a LISP ETR that receives such a packet is not clearly described in [[RFC6830](#)].

An attacker can send a data packet with the L bit set to 1 and some or all Locator Status Bits set to zero. Therefore, by blindly trusting the Locator Status Bits communication going on can be altered or forced to go through a particular set of locators.

5.3.2.2. Attacks using the Map-Version bit

The optional Map-Version bit is used to indicate whether the low-order 24 bits of the first 32 bits longword of the LISP header contain a Source and Destination Map-Version. When a LISP ETR receives a LISP encapsulated packet with the Map-Version bit set to 1, the following actions are taken:

- o It compares the Destination Map-Version found in the header with the current version of its own mapping, in the EID-to-RLOC Database, for the destination EID found in the encapsulated packet. If the received Destination Map-Version is smaller (i.e., older) than the current version, the ETR should apply the SMR procedure described in [[RFC6830](#)] and send a Map-Request with the SMR bit set.
- o If a mapping exists in the EID-to-RLOC Cache for the source EID, then it compares the Map-Version of that entry with the Source Map-Version found in the header of the packet. If the stored mapping is older (i.e., the Map-Version is smaller) than the source version of the LISP encapsulated packet, the xTR should send a Map-Request for the source EID.

An off-path attacker could use the Map-Version bit to force an ETR to send Map-Request messages. The attacker could retrieve the current

source and destination Map-Version for both HA and HB. Based on this information, it could send a spoofed packet with an older Source Map-Version or Destination Map-Version. If the size of the Map-Request message is larger than the size of the smallest LISP-encapsulated packet that could trigger such a message, this could lead to amplification attacks (see [Section 5.4.1](#)).

5.3.2.3. Attacks using the Nonce-Present and the Echo-Nonce bits

The Nonce-Present and Echo-Nonce bits are used when verifying the reachability of a remote ETR. Assume that LR3 wants to verify that LR1 receives the packets that it sends. LR3 can set the Echo-Nonce and the Nonce-Present bits in LISP data encapsulated packets and include a random nonce in these packets. Upon reception of these packets, LR1 will store the nonce sent by LR3 and echo it when it returns LISP encapsulated data packets to LR3.

A spoofing off-path attacker (SA) could interfere with this reachability test by sending two different types of packets:

1. LISP data encapsulated packets with the Nonce-Present bit set and a random nonce and the appropriate source and destination RLOCs.
2. LISP data encapsulated packets with the Nonce-Present and the Echo-Nonce bits both set and the appropriate source and destination RLOCs. These packets will force the receiving ETR to store the received nonce and echo it in the LISP encapsulated packets that it sends.

The first type of packet should not cause any major problem to ITRs. As the reachability test uses a 24 bits nonce, it is unlikely that an off-path attacker could send a single packet that causes an ITR to believe that the ETR it is testing is reachable while in reality it is not reachable. To increase the success likelihood of such attack, the attacker should create a massive amount of packets carrying all possible nonce values.

The second type of packet could be exploited to attack the nonce-based reachability test. Consider a spoofing off-path attacker (SA) that sends a continuous flow of spoofed LISP data encapsulated packets that contain the Nonce-Present and the Echo-Nonce bit and each packet contains a different random nonce. The ETR that receives such packets will continuously change the nonce that it returns to the remote ITR. If the remote ITR starts a nonce-reachability test, this test may fail because the ETR has received a spoofed LISP data encapsulated packet with a different random nonce and never echoes the real nonce. In this case the ITR will consider the ETR not reachable. The success of this test depends on the ratio between the

amount of packets sent by the legitimate ITR and the spoofing off-path attacker (SA).

5.3.2.4. Attacks using the Instance ID bits

LISP allows to carry in its header a 24-bits value called "Instance ID" and used on the ITR to indicate which local Instance ID has been used for encapsulation, while on the ETR can be used to select the forwarding table used for forwarding the decapsulated packet.

The Instance ID increases exposure to attacks ([[RFC6169](#)]) as if an off-path attacker can randomly guess a valid Instance ID value she gets access to network that she might not have access. However, the impact of such attack is directly on end-systems which is out of the scope of this document.

5.4. Attack using the control-plane

In this section, we discuss the different types of attacks that could occur when an off-path attacker sends control-plane packets. We focus on the packets that are sent directly to the ETR and do not analyze the particularities of a LISP mapping system.

5.4.1. Attacks with Map-Request messages

An off-path attacker could send Map-Request packets to a victim ETR. In theory, a Map-Request packet is only used to solicit an answer and as such it should not lead to security problems. However, the LISP specification [[RFC6830](#)] contains several particularities that could be exploited by an off-path attacker.

The first possible exploitation is the P bit. The P bit is used to probe the reachability of remote ETRs. In our reference environment, LR3 could probe the reachability of LR1 by sending a Map-Request with the P bit set. LR1 would reply by sending a Map-Reply message with the P bit set and the same nonce as in the Map-Request message.

A spoofing off-path attacker (SA) could use the P bit to force a victim ETR to send a Map-Reply to the spoofed source address of the Map-Request message. As the Map-Reply can be larger than the Map-Request message, there is a risk of amplification attack. Considering only IPv6 addresses, a Map-Request can be as small as 40 bytes, considering one single ITR address and no Mapping Protocol Data. The Map-Reply instead has a size of $O(12 + (R * (28 + N * 24)))$ bytes, where N is the maximum number of RLOCs in a mapping and R the maximum number of records in a Map-Reply. Since up to 255 RLOCs can be associated to an EID-Prefix and 255 records can be stored in a Map-Reply, the maximum size of a Map-Reply is thus above

1 MB showing a size factor of up to 39,193 between the message sent by the attacker and the message sent by the ETR. These numbers are however theoretical values not considering transport layer limitations and it is more likely that the reply will contain only one record with at most a dozen of locators, giving an amplification factor around 8.

Similarly, if a non-spoofing off-path attacker (NSA) sends a Map-Request with the P bit set, it will receive a Map-Reply with the P bit set.

An amplification attack could be launched by a spoofing off-path attacker (SA) as follows. Consider an attacker SA and EID-Prefix 192.0.2.0/24 and a victim ITR, SA could send spoofed Map-Request messages whose source EID addresses are all the addresses inside 192.0.2.0/24 and source RLOC address is the victim ITR. Upon reception of these Map-Request messages, the ETR would send large Map-Reply messages for each of the addresses inside p/P back to the victim ITR.

The Map-Request message may also contain the SMR bit. Upon reception of a Map-Request message with the SMR bit, an ETR must return to the source of the Map-Request message a Map-Request message to retrieve the corresponding mapping. This raises similar problems as the P bit discussed above except that as the Map-Request messages are smaller than Map-Reply messages, the risk of amplification attacks is reduced. This is not true anymore if the ETR append to the Map-Request messages its own Map-Records. This mechanism is meant to reduce the delay in mapping distribution since mapping information is provided in the Map-Request message.

Furthermore, appending Map-Records to Map-Request messages allows an off-path attacker to generate a (spoofed or not) Map-Request message and include in the Map-Reply portion of the message mapping for EID prefixes that it does not serve.

Moreover, attackers can use Map Resolver and/or Map Server network elements to perform relay attacks. Indeed, on the one hand, a Map Resolver is used to dispatch Map-Request to the mapping system and, on the other hand, a Map Server is used to dispatch Map-Requests coming from the mapping system to ETRs that are authoritative for the EID in the Map-Request.

5.4.2. Attacks with Map-Reply messages

In this section we analyze the attacks that could occur when an off-path attacker sends directly Map-Reply messages to ETRs without using one of the proposed LISP mapping systems.

There are two different types of Map-Reply messages:

Positive Map-Reply: These messages contain a Map-Record binding an EID-Prefix to one or more RLOCs.

Negative Map-Reply: These messages contain a Map-Record for an EID-Prefix with an empty locator-set and specifying an action, which may be either Drop, natively forward, or Send Map-Request.

Positive Map-Reply messages are used to map EID-Prefixes onto RLOCs. Negative map-reply messages are used to indicate non-lisp prefixes. ITRs can, if needed, be configured to send all traffic destined for non-lisp prefixes to a Proxy-ETR.

Most of the security of the Map-Reply messages depends on the 64 bits nonce that is included in a Map-Request and returned in the Map-Reply. If an ETR does not accept Map-Reply messages with an invalid nonce, the risk of attack is acceptable given the size of the nonce (64 bits). However, the nonce only confirms that the map-reply received was sent in response to a map-request sent, it does not validate the contents of that map-reply.

In addition, an attacker could perform EID-to-RLOC Cache overflow attack by de-aggregating (i.e., splitting an EID prefix into artificially smaller EID prefixes) either positive or negative mappings.

In presence of malicious ETRs, overclaiming attacks are possible. Such an attack happens when an ETR replies to a legitimate Map-Request message it received with a Map-Reply message that contains an EID-Prefix that is larger than the prefix owned by the site that encompasses the EID of the Map-Request. For instance if the prefix owned by the site is 192.0.2.0/25 but the Map-Reply contains a mapping for 192.0.2.0/24, then the mapping will influence packets destined to other EIDs than the one the LISP site has authority on.

A malicious ETR might also fragment its EID-to-RLOC database so that ITR's might have to install much more mappings than really necessary. This attack is called de-aggregation attack.

5.4.3. Attacks with Map-Register messages

Map-Register messages are sent by ETRs to indicate to the mapping system the EID prefixes associated to them. The Map-Register message provides an EID prefix and the list of ETRs that are able to provide Map-Replies for the EID covered by the EID prefix.

As Map-Register messages are protected by an authentication mechanism, only a compromised ETR can register itself to its allocated Map Server.

A compromised ETR can perform an overclaiming attack in order to influence the route followed by Map-Requests for EIDs outside the scope of its legitimate EID prefix.

A compromised ETR can also perform a deaggregation attack in order to register more EID prefixes than necessary to its Map Servers.

5.4.4. Attacks with Map-Notify messages

Map-Notify messages are sent by a Map Server to an ETR to acknowledge the good reception and processing of a Map-Register message.

A spoofing attacker compromised ETR can send a Map-Register with the M-bit set and a spoofed source address to force the Map Server to send a Map-Notify message to the spoofed address and then succeed a relay attack. Similarly to the pair Map-Request/Map-Reply, the pair Map-Register/Map-Notify is protected by a nonce making hard for an attacker to inject a falsified notification to an ETR to make this ETR believe that the registration succeeded while it has not.

6. Attack categories

6.1. Intrusion

6.1.1. Description

With an intrusion attack an attacker gains remote access to some resources (e.g., a host, a router, or a network) that are normally denied to her.

6.1.2. Vectors

Intrusion attacks can be mounted using:

- o Spoofing EID or RLOCs
- o Instance ID bits

6.2. Denial of Service (DoS)

6.2.1. Description

A Denial of Service (DoS) attack aims at disrupting a specific targeted service either by exhausting the resources of the victim up to the point that it is not able to provide a reliable service to legit traffic and/or systems or by exploiting vulnerabilities to make the targeted service unable to operate properly.

6.2.2. Vectors

Denial of Service attacks can be mounted using

- o Gleaning
- o Interworking
- o Locator Status Bits
- o Map-Version bit
- o Nonce-Present and Echo-Nonce bits
- o Map-Request message
- o Map-Reply message
- o Map-Register message
- o Map-Notify message

6.3. Eavesdropping

6.3.1. Description

With an eavesdropping attack, the attacker collects traffic of a target through deep packet inspection in order to gain access to restricted or sensitive information such as passwords, session tokens, or any other confidential information. This type of attack is usually carried out in a way such that the target does not even notice the attack. When the attacker is positioned on the path of the target traffic, it is called a Man-in-the-Middle attack. However, this is not a requirement to carry out an eavesdropping attack. Indeed the attacker might be able, for instance through an intrusion attack on a weaker system, either to duplicate or even redirect the traffic, in both cases having access to the raw packets.

6.3.2. Vectors

Eavesdropping attacks can be mounted using

- o Gleaning
- o Locator Status Bits
- o Nonce-Present and the Echo-Nonce bits
- o Map-Request messages
- o Map-Reply messages

7. Recommendations

TBD

8. IANA Considerations

This document makes no request to IANA.

9. Security Considerations

Security considerations are the core of this document and do not need to be further discussed in this section.

10. Acknowledgments

This document builds upon the draft of Marcelo Bagnulo ([[I-D.bagnulo-lisp-threat](#)]), where the flooding attack and the reference environment were first described.

The authors would like to thank Florin Coras, Vina Ermagan, Darrel Lewis, and Jeff Wheeler for their comments.

This work has been partially supported by the INFSO-ICT-216372 TRILOGY Project (www.trilogy-project.org).

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[Appendix A](#). Document Change Log

- o Version 06 Posted October 2013.

- * Complete restructuration, temporary version to be used at October 2013 interim meeting.

- o Version 05 Posted August 2013.

- * Removal of severity levels to become a short recommendation to reduce the risk of the discussed threat.

- o Version 04 Posted February 2013.

- * Clear statement that the document compares threats of public LISP deployments with threats in the current Internet architecture.

- * Addition of a severity level discussion at the end of each section.
- * Addressed comments from V. Ermagan and D. Lewis' reviews.
- * Updated References.
- * Further editorial polishing.
- o Version 03 Posted October 2012.
 - * Dropped Reference to [RFC 2119](#) notation because it is not actually used in the document.
 - * Deleted future plans section.
 - * Updated References
 - * Deleted/Modified sentences referring to the early status of the LISP WG and documents at the time of writing early versions of the document.
 - * Further editorial polishing.
 - * Fixed all ID nits.
- o Version 02 Posted September 2012.
 - * Added a new attack that combines overclaiming and de-aggregation (see [Section 5.4.2](#)).
 - * Editorial polishing.
- o Version 01 Posted February 2012.
 - * Added discussion on LISP-DDT.
- o Version 00 Posted July 2011.
 - * Added discussion on LISP-MS>.
 - * Added discussion on Instance ID in [Section 5.3.2](#).
 - * Editorial polishing of the whole document.
 - * Added "Change Log" appendix to keep track of main changes.
 - * Renamed "[draft-saucez-lisp-security-03.txt](#)".

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