Mobile Ad hoc Networking (MANET)
Internet-Draft
Intended status: Informational
Expires: August 18, 2016

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February 15, 2016

Security Threats for Simplified Multicast Forwarding (SMF)
draft-ietf-manet-smf-sec-threats-04

Abstract

This document analyzes security threats of the Simplified Multicast Forwarding (SMF), including the vulnerabilities of duplicate packet detection and relay set selection mechanisms. This document is not intended to propose solutions to the threats described.

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1. Introduction

This document analyzes security threats to the Simplified Multicast Forwarding (SMF) mechanism [RFC6621]. SMF aims at providing basic Internet Protocol (IP) multicast forwarding, in a way that is suitable for limited wireless mesh and Mobile Ad hoc NETworks (MANET). SMF is constituted of two major functional components: Duplicate Packet Detection and Relay Set Selection.

SMF is typically used in decentralized wireless environments, and is potentially exposed to different kinds of attacks and misconfigurations. Some of the threats are of particular significance as compared to wired networks. In [RFC6621], SMF does not define any explicit security measures for protecting the integrity of the protocol.

This document is based on the assumption that no additional security mechanism such as IPsec is used in the IP layer, as not all MANET deployments may be suitable to deploy common IP protection mechanisms (e.g., because of limited resources of MANET routers to support the IPsec stack). It assumes that there is no lower-layer protection either. The document analyzes possible attacks on and mis-configurations of SMF and outlines the consequences of such attacks/ mis-configurations to the state maintained by SMF in each router.

This document aims at analyzing and describing the potential vulnerabilities of and attack vectors for SMF. While completeness in such analysis is always a goal, no claims of being complete are made. The goal of this document is to be helpful for when deploying SMF in a network and needing to understand the risks thereby incurred - as well as for providing a reference and documented experience with SMF as input for possibly future developments of SMF.

This document is not intended to propose solutions to the threats described. [RFC7182] provides a framework that can be used with SMF, and depending on how it is used - may offer some degree of protection against the threats described in this document related to identity spoofing.

2. Terminology

This document uses the terminology and notation defined in [RFC5444], [RFC6130], [RFC6621] and [RFC4949].

Additionally, this document introduces the following terminology:

SMF router: A MANET router, running SMF as specified in [RFC6621].

Attacker: A device that is present in the network and intentionally seeks to compromise the information bases in SMF routers. It may generate syntactically correct SMF control messages.

Legitimate SMF router: An SMF router that is correctly configured and not compromised by an attacker.

3. SMF Threats Overview

SMF requires an external dynamic neighborhood discovery mechanism in order to maintain suitable topological information describing its immediate neighborhood, and thereby allowing it to select reduced relay sets for forwarding multicast data traffic. Such an external dynamic neighborhood discovery mechanism may be provided by lower-layer interface information, by a concurrently operating MANET routing protocol that already maintains such information such as [RFC7181], or by explicitly using MANET Neighborhood Discovery Protocol (NHDP) [RFC6130]. If NHDP is used for neighborhood discovery by SMF, SMF implicitly inherits the vulnerabilities of NHDP, as discussed in [RFC7186]. As SMF relies on NHDP to assist in network layer 2-hop neighborhood discovery (not matter if other lower-layer mechanisms are used for 1-hop neighborhood discovery), this document assumes that NHDP is used in SMF. The threats that are NHDP-specific are indicated explicitly.

Based on neighborhood discovery mechanisms, SMF specified two major functional components: Duplicate Packet Detection (DPD) and Relay Set Selection (RSS).

DPD is required by SMF in order to be able to detect duplicate packets and eliminate their redundant forwarding. An Attacker has several ways in which to harm the DPD mechanisms:

- o It can "deactivate" DPD, so as to make it such that duplicate packets are not correctly detected, and that as a consequence they are (redundantly) transmitted, increasing the load on the network, draining the batteries of the routers involved, etc.

- o It can "pre-activate" DPD, so as to make DPD detect a later arriving (valid) packet as being a duplicate, which therefore won't be forwarded. "

The attacks on DPD can be achieved by replay existed packets, wrangle sequence numbers, manipulate hash values, etc. They are detailed in Section 4.

RSS produces a reduced relay set for forwarding multicast data packets across the MANET. SMF supports the use of several relay set algorithms, including E-CDS (Essential Connected Dominating Set) [RFC5614], S-MPR (Source-based Multi-point Relay, as known from [RFC3626] and [RFC7181]), or MPR-CDS [MPR-CDS]. An Attacker can disrupt the RSS algorithm by degrading it to classical flooding, or by "masking" certain parts of the routers from the multicasting domain. The attacks to RSS algorithms are illustrated in Section 5.

4. Threats to Duplicate Packet Detection

Duplicate Packet Detection (DPD) is required for packet dissemination in MANETs because: (1) the packets may be transmitted via the same physical interface as the one over which they were received; (2) a router may also receive multiple copies of the same packet from different neighbors. DPD is thus used to check if an incoming packet has been previously received or not.

DPD is achieved by maintaining a record of recently processed multicast packets, and comparing later received multicast packets herewith. A duplicate packet detected is silently dropped and is not inserted into the forwarding path of that router, nor is it delivered to an application. DPD, as proposed by SMF, supports both IPv4 and IPv6 and for each suggests two duplicate packet detection mechanisms: 1) header content identification-based DPD (I-DPD), using packet headers, in combination with flow state, to estimate temporal uniqueness of a packet, and 2) hash-based DPD (H-DPD), employing hashing of selected header fields and payload for the same effect.

In the following of this section, common threats to packet detection mechanisms are first discussed. Then the threats to I-DPD and H-DPD are introduced separately. The threats described in this section are applicable to general SMF implementations, no matter if NHDP is used or not.

4.1. Common Threats to Duplicate Packet Detection Mechanisms

4.1.1. Replay Attack

A replay attack implies that control traffic from one region of the network is recorded and replayed in a different region at (almost) the same time, or in the same region at a different time.

One possible replay attack is based on the Time-to-Live (TTL, for IPv4) or hop limit (for IPv6) field. As routers only forward packets with TTL > 1, an attacker can forward an otherwise valid packet, while drastically reducing the TTL hereof. This will inhibit

recipient routers from later forwarding the same multicast packet, even if received with a different TTL - essentially an attacker thus can instruct its neighbors to block forwarding of valid multicast packets.

For example, in Figure 1, router A forwards a multicast packet with a TTL of 64 to the network. A, B, and C are legitimate SMF routers, and X is the attacker. In a wireless environment, jitter is commonly used to avoid systematic collisions in MAC protocols [RFC5148]. An attacker can thus increase the probability that its invalid packets arrive first by retransmitting them without jittering. In this example, router X forwards the packet without jittering and reduces the TTL to 1. Router C thus records the duplicate detection value (hash value for H-DPD, or the header content of the packets for I-DPD) but stops forwarding it to the next hops because of the TTL value. When the same packet with normal TTL value (63 in this case) arrives from router B, it will be discarded as duplicate packet.

```
                                    .---.
                                    | X |
                                  --'---' __
           packet with TTL=64    /          \  packet with TTL=1
                                /            \
                            .---.              .---.
                            | A |              | C |
                            '---'              '---'
           packet with TTL=64   \    .---.   /
                                 \-- | B |__/  packet with TTL=63
                                     '---'
```

Figure 1

As the TTL of a packet is intended to be manipulated by intermediaries forwarding it, classic methods such as integrity check values (e.g., digital signatures) are typically calculated with setting TTL fields to some pre-determined value (e.g., 0) - such is for example the case for IPsec Authentication Headers - rendering such an attack more difficult to both detect and counter.

If the attacker has access to a "wormhole" through the network (a directional antenna, a tunnel to a collaborator or a wired connection, allowing it to bridge parts of a network otherwise distant), it can make sure that the packets with such an artificially reduced TTL arrive before their unmodified counterparts.

4.2. Threats to Identification-based Duplicate Packet Detection

I-DPD uses a specific DPD identifier in the packet header to identify a packet. By default, such packet identification is not provided by the IP packet header (for both IPv4 and IPv6). Therefore, additional identification headers, such as the fragment header, a hop-by-hop header option, or IPSec sequencing, must be employed in order to support I-DPD. The uniqueness of a packet can then be identified by the source IP address of the packet originator and the sequence number (from the fragment header, hop-by-hop header option, or IPsec). By doing so, each intermediate router can keep a record of recently received packets and determine whether the incoming packet has been received or not.

4.2.1. Pre-activation Attacks (Pre-Play)

In a wireless environment, or across any other shared channel, an attacker can perceive the identification tuple (source IP address, sequence number) of a packet. It is possible to generate a packet with the same (source IP address, sequence number) pair with invalid content. If sequence number progression is predictable, then it is trivial to generate and inject invalid packets with "future" identification information into the network. If these invalid packets arrive before the legitimate packets that they are spoofing, the latter will be treated as a duplicate and discarded. This can prevent multicast packets from reaching parts of the network.

Figure 2 gives an example of pre-activation attack. A, B and C are legitimate SMF routers, and X is the attacker. The line between the routers presents the packet forwarding. Router A is the source and originates a multicast packet with sequence number n. When router X receives the packet, it generates an invalid packet with the source address of A and sequence number n. If the invalid packet arrives at router C before the forwarding of router B, the valid packet will be dropped by C as a duplicate packet. An attacker can manipulate jitter to make sure that the invalid packets arrive first. Router X can even generate packets with future sequence numbers (if they are predictable), so that the future legitimate packets with the same sequence numbers will be dropped as duplicate ones.

```
                                .---.
                                | X |
                              --'---' __
       packet with seq=n     /          \  invalid packet with seq=n
                            /            \
                        .---.              .---.
                        | A |              | C |
                        '---'              '---'
       packet with seq=n    \    .---.   /
                             \-- | B |__/  valid packet with seq=n
                                 '---'
```

Figure 2

As SMF currently does not have any timestamp mechanisms to protect data packets, there is no viable way to detect such pre-play attacks by way of timestamps. Especially, if the attack is based on manipulation of jitter, the validation of timestamp would not be helpful because the timing is still valid (but with much less value).

4.2.2. De-activation Attacks (Sequence Number wrangling)

An attacker can also seek to de-activate DPD, by modifying the sequence number in packets that it forwards. Thus, routers will not be able to detect an actual duplicate packet as a duplicate - rather, they will treat them as new packets, i.e., process and forward them. This is similar to DoS attacks. The consequence of this attack is an increased channel load, the origin of which appears to be a router other than the attacker.

Given the topology shown in Figure 2, on receiving a packet with seq=n, the attacker X can forward the packet with modified sequence number n+i. This has two consequences: firstly, router C will not be able to detect the packet forwarded by X is a duplicate packet; secondly, the consequent packet with seq=n+i generated by router A probably will be treated as duplicate packet, and dropped by router C.

4.3. Threats to Hash-based Duplicate Packet Detection

When explicit sequence numbers in packet headers is undesired, hash-based DPD can be used. A hash of the non-mutable fields in the header of and the data payload can be generated, and recorded at the intermediate routers. A packet can thus be uniquely identified by the source IP address of the packet and its hash-value.

The hash algorithm used by SMF is being applied only to provide a

reduced probability of collision and is not being used for cryptographic or authentication purposes. Consequently, a digest collision is still possible. In case the source router or gateway identifies that it recently has generated or injected a packet with the same hash-value, it inserts a "Hash-Assist Value (HAV)" IPv6 header option into the packet, such that calculating the hash also over this HAV will render the resulting value unique.

4.3.1. Attack on Hash-Assistant Value

The HAV header is helpful when a digest collision happens. However, it also introduces a potential vulnerability. As the HAV option is only added when the source or the ingress SMF router detects that the coming packet has digest collision with previously generated packets, it actually can be regarded as a "flag" of potential digest collision. An attacker can discover the HAV header, and be able to conclude that a hash collision is possible if the HAV header is removed. By doing so, the modified packet received by other SMF routers will be treated as duplicate packets, and be dropped because they have the same hash value with the precedent packet.

In the example of Figure 3, Router A and B are legitimate SMF routers; X is an attacker. A generates two packets P1 and P2, with the same hash value h(P1)=h(P2)=x. Based on the SMF specification, a hash-assistant value (HAV) is added to the latter packet P2, so that h(P2+HAV)=x', to avoid digest collision. When the attacker X detects the HAV of P2, it is able to conclude that a collision is possible by removing the HAV header. By doing so, packet P2 will be treated as duplicate packet by router B, and be dropped.

```
              P2            P1                P2         P1
   .---.  h(P2+HAV)=x'    h(P1)=x    .---.  h(P2)=x     h(P1)=x    .---.
   | A |--------------------------->  | X | ----------------------> | B |
   `---'                              `---'                          `---'
```

Figure 3

5. Threats to Relay Set Selection

A framework for RSS mechanism, rather than a specific RSS algorithm is provided by SMF. It is normally achieved by distributed algorithms that can dynamically generate a topological Connected Dominating Set based on 1-hop and 2-hop neighborhood information. In this section, the common threats to the RSS framework are first

discussed. Then the three commonly used algorithms: Essential Connection Dominating Set (E-CDS) algorithm, Source-based Multipoint Relay (S-MPR) and Multipoint Relay Connected Dominating Set (MPR-CDS) are analyzed. As the relay set selection is based on 1-hop and 2-hop neighborhood information, which rely on NHDP, the threats described in this section are NHDP-specific.

5.1. Relay Set Selection Common Threats

The common threats to RSS algorithms, including Denial of Service attack, eavesdropping, message timing attack and broadcast storm have been discussed in [RFC7186].

5.2. Threats to E-CDS Algorithm

The "Essential Connected Dominating Set" (E-CDS) algorithm [RFC5614] forms a single CDS mesh for the SMF operating region. It requires 2-hop neighborhood information (the identify of the neighbors, the link to the neighbors and neighbors' priority information) collected through NHDP or another process.

An SMF Router select itself as a relay, if:

- The SMF Router has a higher priority than all of its symmetric neighbors, or
- There does not exist a path from the neighbor with largest priority to any other neighbor, via neighbors with greater priority.

An attacker can disrupt the E-CDS algorithm by link spoofing or identity spoofing.

5.2.1. Link Spoofing

Link spoofing implies that an attacker advertises non-existing links to another router (present in the network or not).

An attacker can declare itself with high route priority, and spoofs the links to as many legitimate SMF Routers as possible to declare high connectivity. By doing so, it can prevent legitimate SMF Routers from self-selecting as relays. As the "super" relay in the network, the attacker can manipulate the traffic relayed by it.

5.2.2. Identity Spoofing

Identity spoofing implies that an attacker determines and makes use of the identity of other legitimate routers, without being authorized

to do so. The identity of other routers can be obtained by overhearing the control messages or the source/destination address from datagrams. The attacker can then generate control or datagram traffic, pretending to be a legitimate router.

Because E-CDS self-selection is based on the router priority value, an attacker can spoof the identity of other legitimate routers, and declares a different router priority value. If it declares a higher priority of a spoofed router, it can prevent other routers from selecting themselves as relays. On the other hand, if the attacker declares lower priority of a spoofed router, it can enforce other routers to selecting themselves as relays, to degrade the multicast forwarding to classical flooding.

5.3. Threats to S-MPR Algorithm

The source-based multipoint relay (S-MPR) set selection algorithm enables individual routers, using 2-hop topology information, to select relays from their set of neighboring routers. MPRs are selected so that forwarding to the router's complete 2-hop neighbor set is covered.

An SMF router forwards a multicast packet if and only if:

- the packet has not been received received before, and

- the neighbor from which the packet was received has selected the router as MPR.

Because MPR calculation is based on the willingness declared by the SMF routers, and the connectivity of the routers, it can be disrupted by both link spoofing and identity spoofing. The threats and its impacts have been illustrated in section 5.1 of [RFC7186].

5.4. Threats to MPR-CDS Algorithm

MPR-CDS is a derivative from S-MPR. The main difference between S-MPR and MPR-CDS is that while S-MPR forms a different broadcast tree for each source in the network, MPR-CDS forms a unique broadcast tree for all sources in the network.

As MPR-CDS combines E-CDS and S-MPR and the simple combination of the two algorithms does not address the weakness, the vulnerabilities of E-CDS and S-MPR that discussed in Section 5.2 and Section 5.3 apply to MPR-CDS also.

6. Future Work

Neither [RFC6621] nor this document propose mechanisms to secure the SMF protocol. However, this section aims at discussing possibilities to secure the protocol in the future and driving new work by suggesting which threats discussed in the previous sections could be addressed.

For the I-DPD mechanism, employing randomized packet sequence numbers can avoid some pre-activation attacks based on sequence number prediction. If predicable sequence numbers have to be used, applying timestamps can mitigate pre-activation attacks.

If NHDP is used as the neighborhood discovery protocol, [RFC7183] is recommended to be implemented to enable integrity protection to NHDP, which can help mitigating the threats related to identity spoofing through the exchange of HELLO messages. It provides certain protection against identity spoofing by admitting only trusted routers to the network using Integrity Check Values (ICVs) in HELLO messages based on shared keys.

However, using ICVs does not address the problem of attackers that can generate valid ICVs. Detecting such attackers could be studied in new work. The shared key mechanism makes excluding single attackers routers difficult. Work could be done to facilitate revocation mechanisms in certain MANET use cases where routers have sufficient capabilities to support asymmetric keys (such as [I-D.ietf-manet-ibs]).

As [RFC7183] does not protect the integrity of the multicast datagram, and no mechanism is specified to do that for SMF yet, the duplicate packet detection is still vulnerable to the threats introduced in Section 4.

If pre-activation/de-activation attacks and attack on hash-assistant value of the multicast datagrams are to be mitigated, a datagram-level integrity protection mechanism is desired, by taking consideration of the identity field or hash-assistant value. However, this would not be helpful for the attacks on the TTL (or hop limit for IPv6) field, because the mutable fields are generally not considered when ICV is calculated.

7. Security Considerations

This document does not specify a protocol or a procedure. The whole document, however, reflects on security considerations for SMF for packet dissemination in MANETs.

8. IANA Considerations

This document contains no actions for IANA.

[RFC Editor: please remove this section prior to publication.]

9. Acknowledgments

The authors would like to thank Christopher Dearlove (BAE Systems ATC) who provided detailed review and valuable comments.

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