Security Assessment of Neighbor Discovery for IPv6

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project carried out on behalf of

UK Centre for the Protection of National Infrastructure

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Agenda

- Ongoing work on IPv6 security at UK CPNI
- IPv6 Address resolution mechanism
- Attacks against the address resolution mechanism
- IPv6 Stateless Address Auto-Configuration (SLAAC)
- Attacks against SLAAC
- Router Advertisement Guard (RA-Guard) evasion
- Conclusions
- Questions (and hopefully answers ☺)

Ongoing work on IPv6 security at UK CPNI

Ongoing work on IPv6 security at CPNI

- The UK CPNI (Centre for the Protection of National Infrastructure) is currently working on a security assessment of the IPv6 protocol suite
- Similar project to the one we carried out years ago on TCP and IPv4:
  - Security assessment of the protocol specifications
  - Security assessment of common implementation strategies
  - Production of assessment/Proof-Of-Concept tools
  - Publication of “best practices” documents
- Currently cooperating with vendors and other parties
- If you’re working on a IPv6 implementation, have hardware that you can let me play with, I’d like to hear from you

Neighbor Discovery in IPv6

Neighbor Discovery in IPv6

- Neighbor Discovery is employed for Address Resolution and Stateless Address Autoconfiguration (SLAAC)
- It is based on ICMPv6 messages
- It implements a similar functionality to that provided in IPv4 by the ARP and DHCPv4

Address Resolution in IPv6

Address Resolution in IPv6

- Employs Neighbor Solicitation and Neighbor Advertisement messages.
- The process is simple:
  1. Node 1 sends a NS: Who has IPv6 address 2001:db8::1?
  2. Node 2 responds with a NA: I have address 2001:db8::1, and the Link-layer address is 06:09:12:cf:db:55.
  3. Node 1 caches the received information in the “Neighbor Cache” for a while (an optimization)
  4. Node 1 can now send packets to Node 2

Neighbor Solicitation messages

- Used to request the Link-layer address of an IPv6 node.
- The only allowed option is the Source Link-layer address option

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |     Type      |     Code      |          Checksum             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           Reserved                            |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                                                               |
//                       Target Address                          //
 |                                                               |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Options ...
 +-+-+-+-+-+-+-+-+-+-+-+-
```

Neighbor Advertisement messages

- Used to respond with the Link-layer address of an IPv6 node.
- The only allowed option is the Target Link-layer address option

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |     Type      |     Code      |          Checksum             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           Reserved                            |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                                                               |
//                       Target Address                          //
 |                                                               |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Options ...
 +-+-+-+-+-+-+-+-+-+-+-+-+-
```

Source/Target Link-layer address option

- The Source Link-layer address option contains the link-layer address of the IPv6 Source Address of the packet
- The Target Link-layer address contains the link-layer address of the “Target Address” of a Neighbor Solicitation message

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |    Length     |    Link-Layer Address ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type: 1 for Source Link-layer Address
2 for Target Link-layer Address

Address Resolution in IPv6

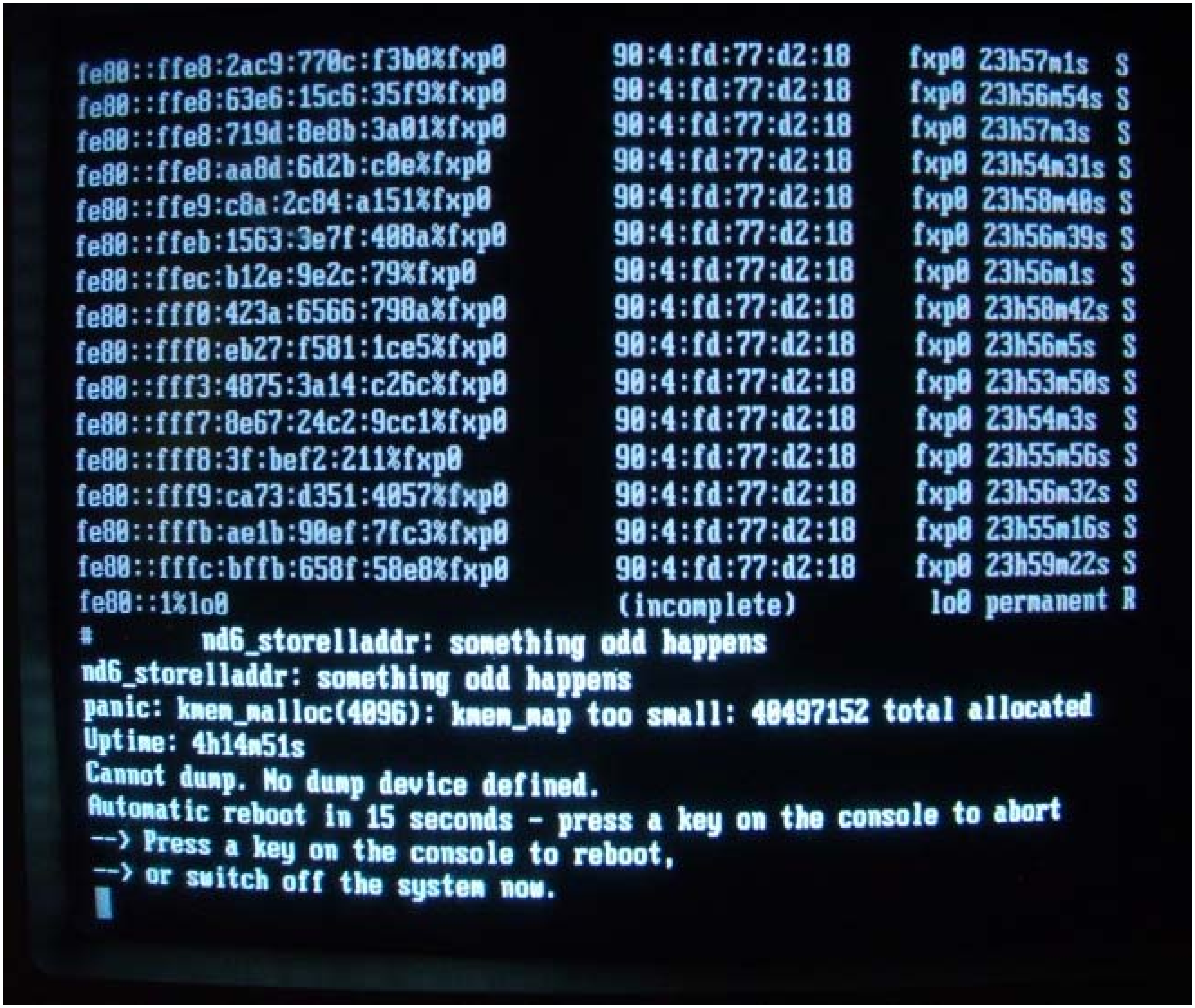
(a sample attack…)

All work and no play makes Jack a dull boy.....

Overflowing the Neighbor Cache

- Some implementations fail to enforce limits on the number of entries in the Neigbor Cache
- Attack:
  - □ Send tons of Neighbor Solicitation messages that include a Source Link-layer address option
  - □ For each packet, the target system adds an entry in the Neighbor Cache
  - □ If entries are added at a higher rate than they are garbage-collected…

Overflowing the Neighbor Cache (II)



```
fe80::ffe8:2ac9:770c:f3b0%fxp0          90:4:fd:77:d2:18     fxp0 23h57m1s   S
fe80::ffe8:63e6:15c6:35f9%fxp0          90:4:fd:77:d2:18     fxp0 23h56m54s  S
fe80::ffe8:719d:8e8b:3a01%fxp0          90:4:fd:77:d2:18     fxp0 23h57m3s   S
fe80::ffe8:aa8d:6d2b:c0e%fxp0           90:4:fd:77:d2:18     fxp0 23h54m31s  S
fe80::ffe9:c8a:2c84:a151%fxp0           90:4:fd:77:d2:18     fxp0 23h58m40s  S
fe80::ffeb:1563:3e7f:408a%fxp0          90:4:fd:77:d2:18     fxp0 23h56m39s  S
fe80::ffec:b12e:9e2c:79%fxp0            90:4:fd:77:d2:18     fxp0 23h56m1s   S
fe80::fff0:423a:6566:798a%fxp0          90:4:fd:77:d2:18     fxp0 23h58m42s  S
fe80::fff0:eb27:f581:1ce5%fxp0          90:4:fd:77:d2:18     fxp0 23h56m5s   S
fe80::fff3:4875:3a14:c26c%fxp0          90:4:fd:77:d2:18     fxp0 23h53m50s  S
fe80::fff7:8e67:24c2:9cc1%fxp0          90:4:fd:77:d2:18     fxp0 23h54m3s   S
fe80::fff8:3f:bef2:211%fxp0             90:4:fd:77:d2:18     fxp0 23h55m56s  S
fe80::fff9:ca73:d351:4857%fxp0          90:4:fd:77:d2:18     fxp0 23h56m32s  S
fe80::fffb:ae1b:90ef:7fc3%fxp0          90:4:fd:77:d2:18     fxp0 23h55m16s  S
fe80::fffc:bffb:658f:58e8%fxp0          90:4:fd:77:d2:18     fxp0 23h59m22s  S
fe80::1%lo0                             (incomplete)          lo0 permanent  R
#       nd6_storelladdr: something odd happens
nd6_storelladdr: something odd happens
panic: kmem_malloc(4096): kmem_map too small: 40497152 total allocated
Uptime: 4h14m51s
Cannot dump. No dump device defined.
Automatic reboot in 15 seconds - press a key on the console to abort
--> Press a key on the console to reboot,
--> or switch off the system now.
```

Man in the Middle or Denial of Service

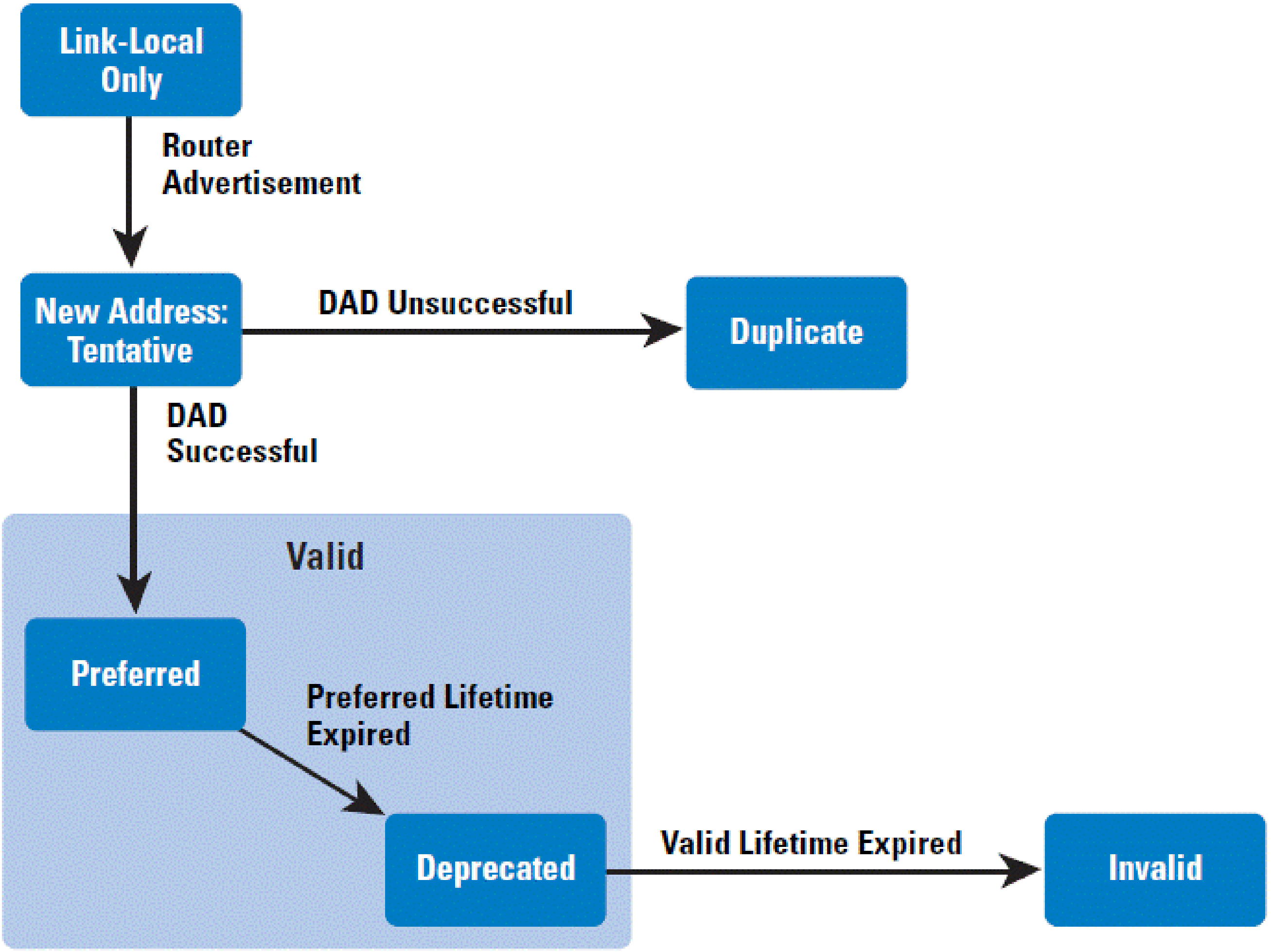
- If no athentication is in place, node impersonation becomes trivial
- Attack:
  - Just listen for Neighbor Solicitation messages for the victim host
  - Forge a Neighbor Advertisement when a solicitation is received
- If the forged “Target Link-layer address” is non-existent, traffic is black-holed, and hence a DoS is achieved
- If the forged “Target Link-layer address” is that of the attacker’s box, he can perform a Man In The Middle (MITM) attack

Stateless Address Autoconfiguration in IPv6

Stateless Address Autoconfiguration

- It roughly works as follows:
  1. The host configures a link-local address
  2. It checks that the address is unique – i.e., performs Duplicate Address Detection (DAD) for that address
     - Send a NS, and wait to see if a NA arrives
  3. The host sends a Router Solicitation message
  4. When a response is received, a tentative address is configured
  5. The tentative address is checked for uniqueness – i.e., Duplicate Address Detection (DAD) is performed for that address
     - Send a NS, and wait to see if a NA arrives
  6. If it’s unique, the address becomes a valid address

SLAAC Flowchart



Router Solicitation messages

- They are ICMPv6 messages of Type 133, Code 0
- Used for soliciting a local router network configuration
- The only option that is currently allowed in RS messages is the Source Link-layer Address option

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Type     |      Code     |          Checksum             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Reserved                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Options ...
+-+-+-+-+-+-+-+-+-+-+-+-
```

Router Advertisement messages

- They are ICMPv6 messages of Type 134, Code 0
- Used for soliciting a local router network configuration

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |     Code      |          Checksum             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Cur Hop Limit |M|O|H|Prf|Resvd|       Router Lifetime         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Reachable Time                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Retrans Timer                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Options ...
+-+-+-+-+-+-+-+-+-+-+-+-
```

Allowed options in RA messages

- The current specifications allow RA messages to contain any of the following options:
  - Source Link-layer address
  - Prefix Information
  - MTU
  - Route Information
  - Recursive DNS Server

Prefix Information option

- Used to specify on-link prefixes and prefixes for autoconfiguration

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |     Type      |    Length     | Prefix Length |L|A|R|Reserved1|
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                         Valid Lifetime                        |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                       Preferred Lifetime                      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           Reserved2                           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                                                               |
//                           Prefix                              //
 |                                                               |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

SLAAC for IPv6

a few sample attacks…

All work and no play makes Jack a dull boy.....

Denial of Service

- Play with Duplicate Address Detection
  - Listen for Neighbor Solicitation messages that use the unspecified address (::) as the IPv6 Source Address
  - When a Solicitation is received, respond with a Neighbor Advertisement
  - As a result, the address will be considered non-unique, and DAD will fail.

- “Disable” an existing router
  - Impersonate the local router, and send a Router Advertisement with a “Router Lifetime” of 0 (or other small value)

Router Advertisement Guard (RA-Guard)

Placebo Security

Router Advertisement Guard

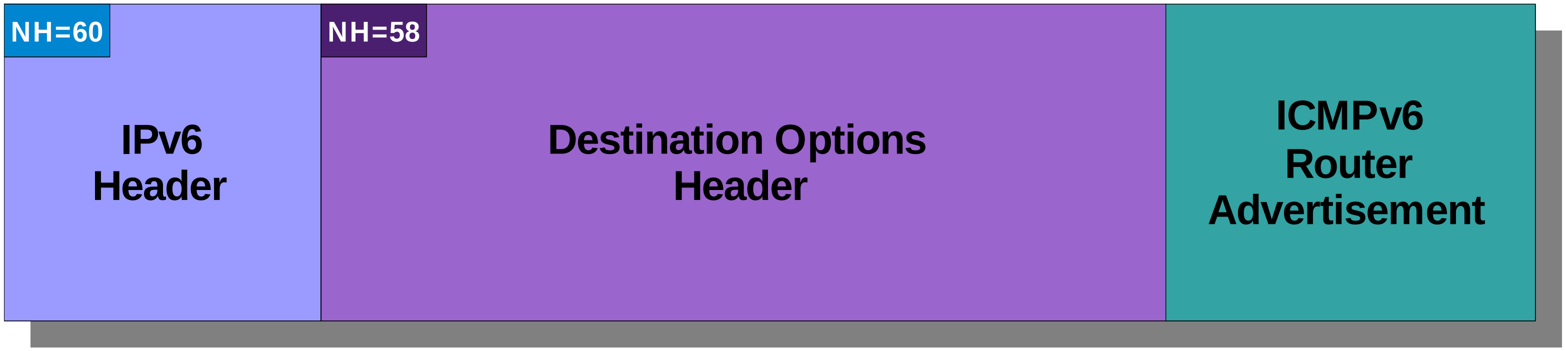
- Many organizations use “Router Advertisement Guard” as the first line of defence for Neighbor Discovery attacks
- RA-Guard works (roughly) as follows:
  - A layer-2 device is configured such that Router Advertisement messages are allowed if they arrive on a specified port
  - RA messages received on other ports are blocked
- It relies on the RA-Guard box’s ability to identify Router Advertisement messages

Router Advertisement Guard evasion

Making the RA-Guard box's life painfull

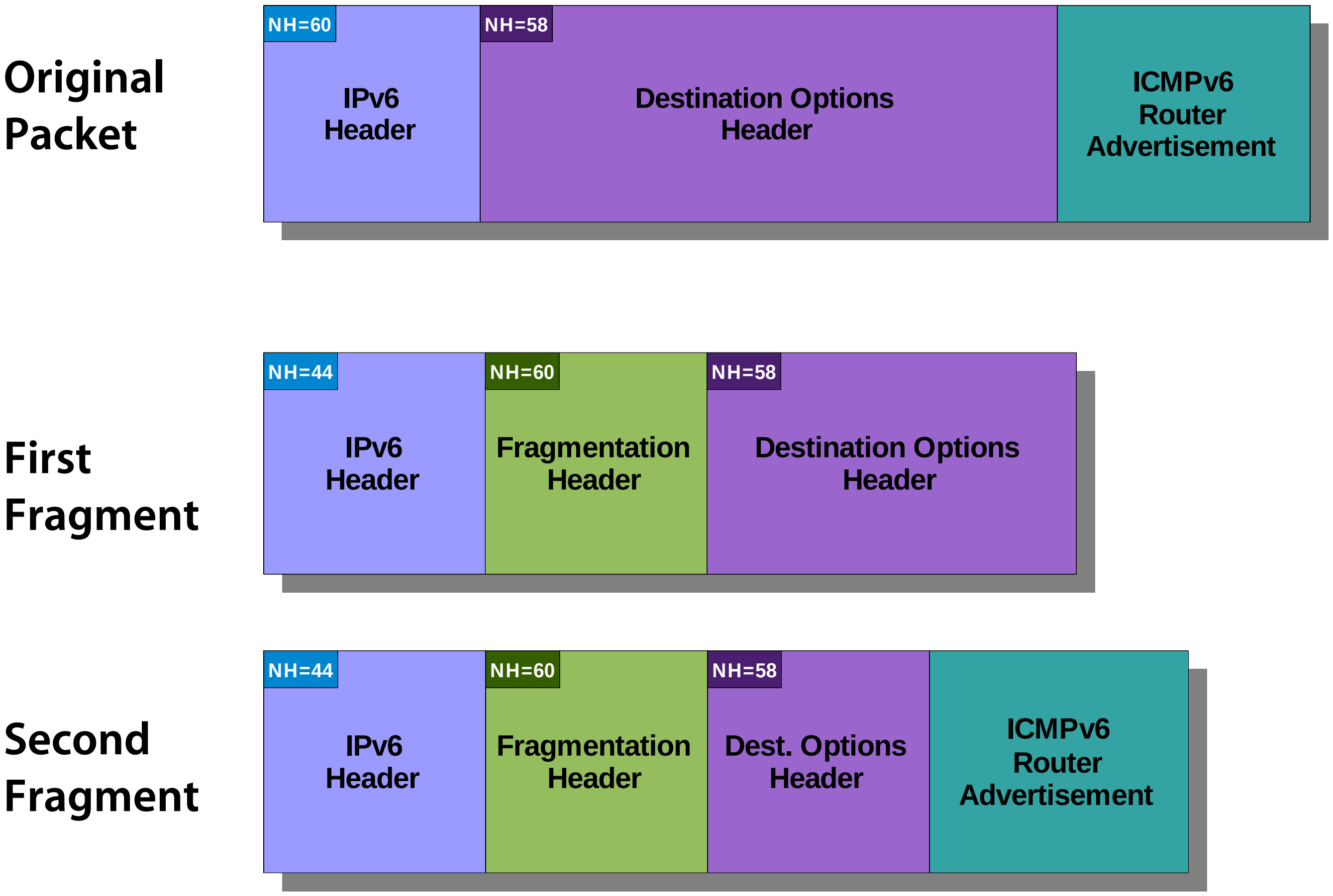
Problem statement

- The protocol specifications allow (and implementations support it) use of multiple extension headers – even multiple instances of the same extension header type.
- The resulting packet structure becomes complex, and it becomes difficult to implement packet filtering.
- Example:



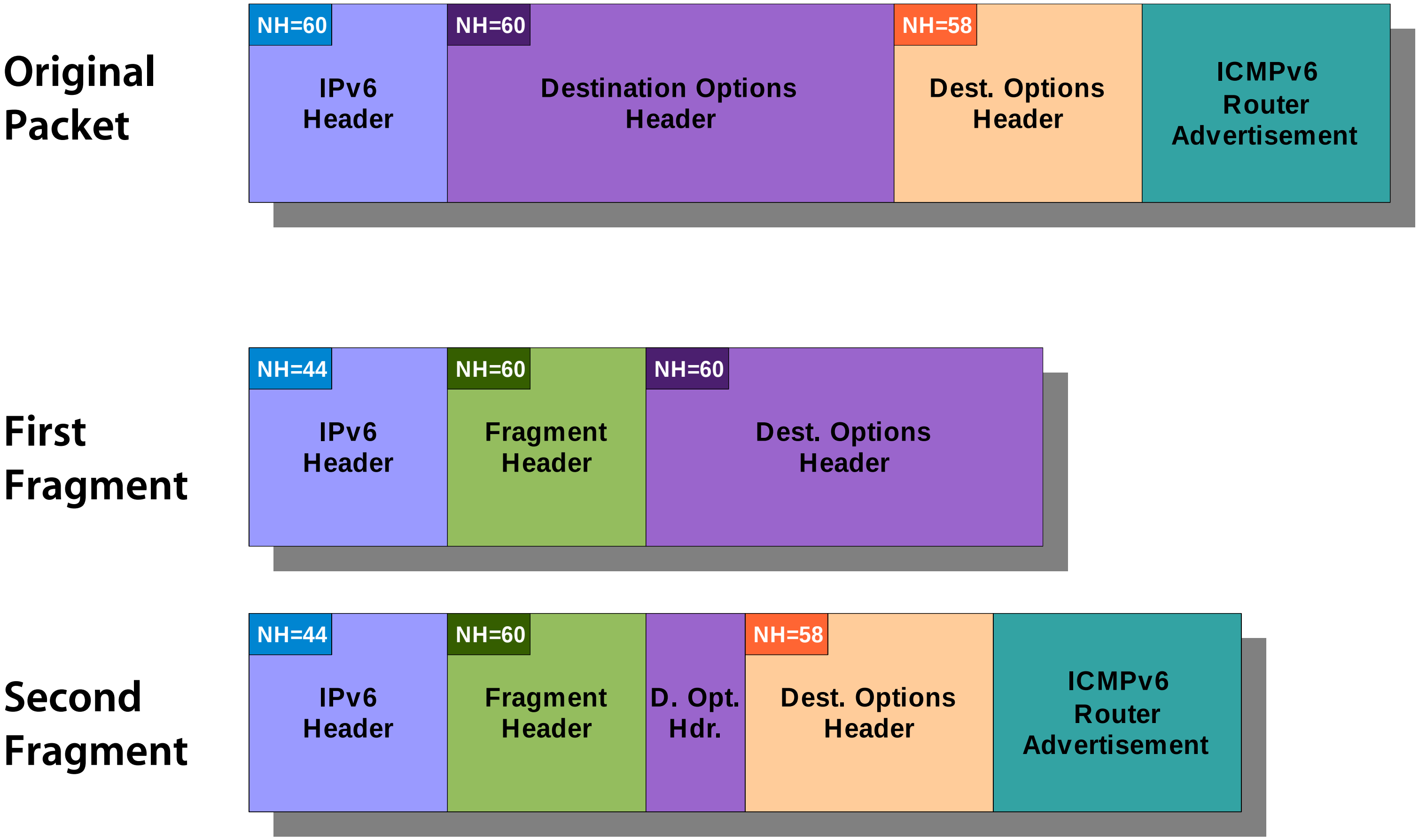
Problem statement (II) The Bad

- Combination of Destination Options header and fragmentation:



Problem statement (III) The Ugly

- Two Destination Options header, and fragmentation:



Original Packet

NH=60 IPv6 Header | NH=60 Destination Options Header | NH=58 Dest. Options Header | ICMPv6 Router Advertisement

First Fragment

NH=44 IPv6 Header | NH=60 Fragment Header | NH=60 Dest. Options Header

Second Fragment

NH=44 IPv6 Header | NH=60 Fragment Header | D. Opt. Hdr. | NH=58 Dest. Options Header | ICMPv6 Router Advertisement

Results

- Even a simple Destination Options header breaks simple implementations of RA Guard
- A combination of fragmentation makes it impossible for a layer-2 device to event detect that a Router Advertisement message is traversing the device (i.e., “Game Over”)

Conclusions

- Clearly, it will take a long time till the maturity of IPv6 implementations matches that of IPv4 implementations.
- It is dangerous that organizations deploy technologies and “mitigations” without a deep understanding of them.

Questions?

Acknowledgements

- UK CPNI, LACNIC, y ISOC

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