# Recent Advances in IPv6 Security

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# About...

- Security researcher and consultant at SI6 Networks
- Have worked on security assessment on communications protocols for:
  - UK NISCC (National Infrastructure Security Co-ordination Centre)
  - UK CPNI (Centre for the Protection of National Infrastructure)
- Active participant at the IETF (Internet Engineering Task Force)
- More information available at: http://www.gont.com.ar

# Agenda

- Disclaimer
- Motivation for this presentation
- Recent Advances in IPv6 Security
  - IPv6 Addressing
  - IPv6 Fragmentation & Reassembly
  - IPv6 First Hop Security
  - IPv6 Firewalling
  - Mitigation to some Denial of Service attacks
- Conclusions
- Questions and Answers

# Disclaimer

- This talks assumes:
  - You know the basics of IPv4 security
  - You now the basics about IPv6 security
  - (i.e. I'm not doing an “IPv6 primer” in this presentation, sorry)
- Much of this is “work in progress” → your input is welcome!
- No “0-days”, sorry.

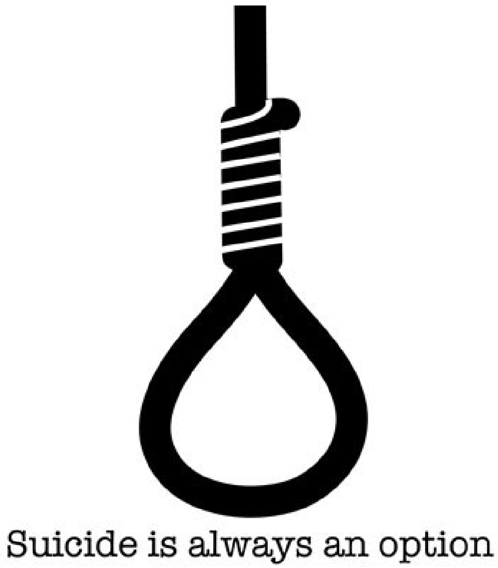
# Motivation for this presentation

# Motivation for this presentation

- Sooner or later you will need to deploy IPv6
  - In fact, you have (at least) partially deployed it, already
- IPv6 represents a number of challenges: What can we do about them?

Option #1

Option #2




Option #3

# Motivation for this presentation (II)

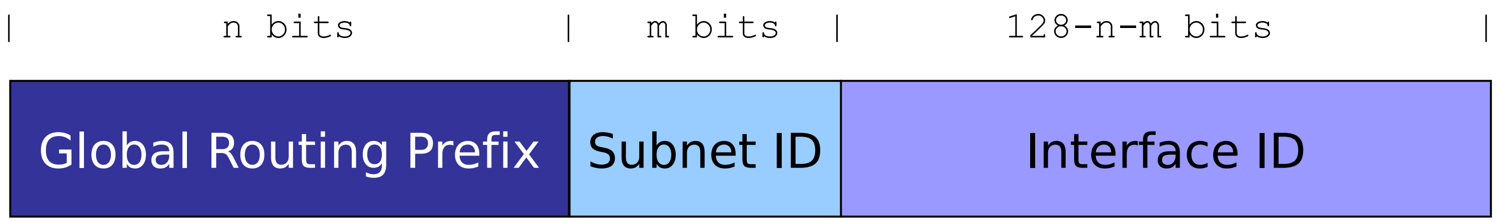
- We have been doing a fair share of IPv6 security research
  - Identification of problems
  - Proposals to mitigate those problems
  - Production of IPv6 security assessment tools
- Almost everything available at: http://www.si6networks.com
- Part of our research has been taken to the IETF
- This talk is about our ongoing work to improve IPv6 security

# Advances in IPv6 Addressing

# Brief overview

- Main driver for IPv6 deployment
- Employs 128-bit addresses
- Address semantics similar to those of IPv4:
  - Addresses are aggregated intro “prefixes”
  - Several address types
  - Several address scopes
- Each interface typically employs more than one address, of different type/scope:
  - One link-local unicast address
  - One or more global unicast addresses
  - etc.

# Global Unicast Addresses




- The “Interface ID” is typically 64-bit long
- Can be selected with different criteria:
  - Modified EUI-64 Identifiers
  - Privacy addresses
  - Manually configured
  - As specified by transition/co-existence technologies

# IPv6 Addressing

## Implications on remote address scanning attacks

# IPv6 remote address scanning attacks

"Thanks to the increased IPv6 address space, IPv6 host scanning attacks are unfeasible. Scanning a /64 would take 500.000.000 years"

– Urban legend

**Is the search space for a /64 really $2^{64}$ addresses?**

# IPv6 addresses in the real world

- Malone measured (*) the address generation policy of hosts and routers in real networks

| Address type | Percentage |
|---|---|
| SLAAC | 50% |
| IPv4-based | 20% |
| Teredo | 10% |
| Low-byte | 8% |
| Privacy | 6% |
| Wordy | <1% |
| Others | <1% |

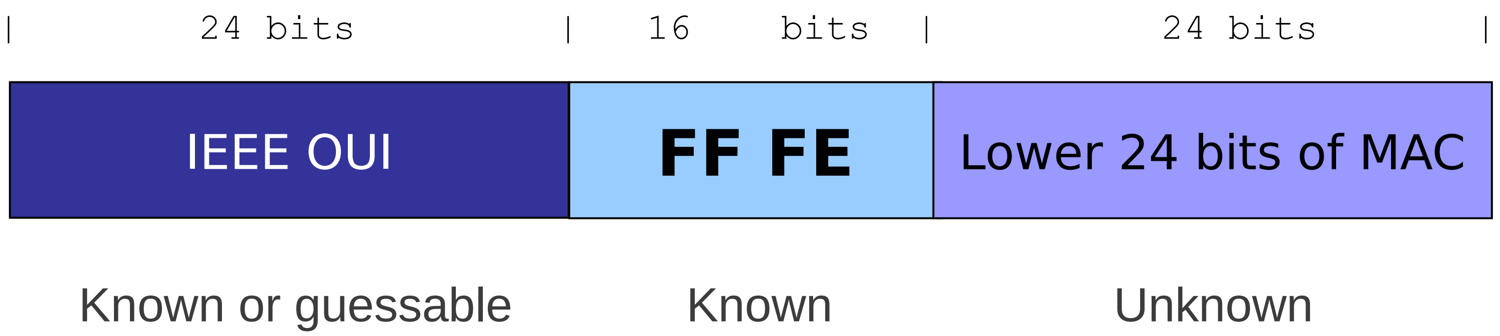
Hosts

| Address type | Percentage |
|---|---|
| Low-byte | 70% |
| IPv4-based | 5% |
| SLAAC | 1% |
| Wordy | <1% |
| Privacy | <1% |
| Teredo | <1% |
| Others | <1% |

Routers

Malone, D., "Observations of IPv6 Addresses", Passive and Active Measurement Conference (PAM 2008, LNCS 4979), April 2008, <http://www.maths.tcd.ie/~dwmalone/p/addr-pam08.pdf>.

# IPv6 addresses embedding IEEE IDs




- In practice, the search space is at most ~$2^{24}$ bits – **feasible!**
- The low-order 24-bits are not necessarily random:
  - An organization buys a large number of boxes
  - In that case, MAC addresses are usually consecutive
  - Consecutive MAC addresses are generally in use in geographically-close locations

# IPv6 addresses embedding IEEE IDs (II)

- Virtualization technologies present an interesting case
- Virtual Box employs OUI 08:00:27 (search space: ~$2^{24}$)
- VMWare ESX employs:
  - Automatic MACs: OUI 00:05:59, and next 16 bits copied from the low order 16 bits of the host's IPv4 address (search space: ~$2^{8}$)
  - Manually-configured MACs:OUI 00:50:56 and the rest in the range 0x000000-0x3fffff (search space: ~$2^{22}$)

# IPv6 addresses embedding IPv4 addr.

- They simply embed an IPv4 address in the IID
  - e.g.: 2000:db8::192.168.0.1
- Search space: same as the IPv4 search space

# IPv6 “low-byte” addresses

- The IID is set to all-zeros, except for the last byte
  - e.g.: 2000:db8::1
  - There are other variants
- Search space: usually $2^8$ or $2^{16}$

# Industry mitigations for scanning attacks

- Microsoft replaced the MAC-address-based identifiers with (non-standard) randomized IIDs
  - Essentially RFC 4941, but they don't vary over time
- Certainly better than MAC-address-based IIDs, but still not “good enough”
- They mitigate host-scanning, but **not** host tracking – constant IIDs are still present!

# Thoughts on remote scanning attacks

- IPv6 host scanning attacks are **feasible**, but typically harder than in IPv4
- They require more “intelligence” on the side of the attacker
- It is **possible** to make them infeasible
- It is likely that many other scanning strategies/techniques will be explored

# IPv6 Addressing

## Implications on privacy

# Problem statement

- Modified EUI-64 IIDs are constant for each interface
- As the host moves, the prefix changes, but the IID doesn't
  - the 64-bit IID results in a super-cookie!
- This introduces a problem not present in IPv4: **host-tracking**
- Example:
  - In net #1, host configures address: 2001:db8:1::1111:2222:3333:4444
  - In net #2, host configures address: 2001:db8:2::1111:2222:3333:4444
  - The IID “1111:2222:3333:4444” leaks out host “identity”.

# “Mitigation” to host-tracking

- RFC 4941: privacy/temporary addresses
  - Random IIDs that change over time
  - Generated **in addition** to traditional SLAAC addresses
  - Traditional addresses used for server-like communications, temporary addresses for client-like communications
- Operational problems:
  - Makes event correlation very difficult!
  - We have helped with that, though: http://www.si6networks.com/tools
- Security problems:
  - They mitigate host-tracking **only partially**
  - They **do not** mitigate address-scanning attacks

# IPv6 addressing

## Mitigating scanning and privacy issues

# Auto-configuration address/ID types

| | Stable | Temporary |
|---|---|---|
| **Predictable** | IEEE ID-derived | None |
| **Unpredictable** | **NONE** | RFC 4941 |

- We lack stable privacy-enhanced IPv6 addresses
  - Used to replace IEEE ID-derived addresses
  - Pretty much orthogonal to privacy addresses
  - Probably “good enough” in most cases even without RFC 4941

# Stable privacy-enhanced addresses

- draft-ietf-6man-stable-privacy-addresses proposes to generate Interface IDs as:

**F**(Prefix, Interface_Index, Network_ID, Secret_Key)

- Where:
  - F() is a PRF (e.g., a hash function)
  - Prefix SLAAC or link-local prefix
  - Interface_Index is the (internal) small number that identifies the interface
  - Network_ID could be e.g. the SSID of a wireless network
  - Secret_Key is unknown to the attacker (and randomly generated by default)

# Stable privacy-enhanced addresses (II)

- As a host moves:
  - Prefix and Network_ID change from one network to another
  - But they remain constant within each network
  - F() varies across networks, but remains constant within each network
- This results in addresses that:
  - Are stable within the same subnet
  - Have different Interface-IDs when moving across networks
  - For the most part, they have “the best of both worlds”
- Document already accepted as a 6man wg item

# IPv6 Fragmentation and Reassembly

# IPv6 fragmentation

- IPv6 fragmentation performed only by hosts (never by routers)
- Fragmentation support implemented in “Fragmentation Header”
- Fragmentation Header syntax:

| 8 bits | 8 bits | 13 bits | 2b | 1b |
|---|---|---|---|---|
| Next Header | Reserved | Fragment Offset | Res | M |
| Identification | | | | |

# Fragment Identification

- Security Implications of predictable Fragment IDs well-known from the IPv4 world
  - idle-scanning, DoS attacks, etc.
- Amount of fragmented traffic will probably increase as a result of:
  - Larger addresses
  - DNSSEC
- But no worries, since we learned the lesson from the IPv4 world... – **right?**

# Fragment ID generation policies

| Operating System | Algorithm |
| --- | --- |
| FreeBSD 9.0 | Randomized |
| NetBSD 5.1 | Randomized |
| OpenBSD-current | Randomized (based on SKIPJACK) |
| Linux 3.0.0-15 | Predictable (GC init. to 0, incr. by +1) |
| Linux-current | Unpredictable (PDC init. to random value) |
| Solaris 10 | Predictable (PDC, init. to 0) |
| Windows 7 Home Prem. | Predictable (GC, init. to 0, incr. by +2) |

GC: Global Counter  PDC: Per-Destination Counter

At least Solaris and Linux patched in response to our IETF I-D – more patches expected!

# Fixing predictable Fragment IDs

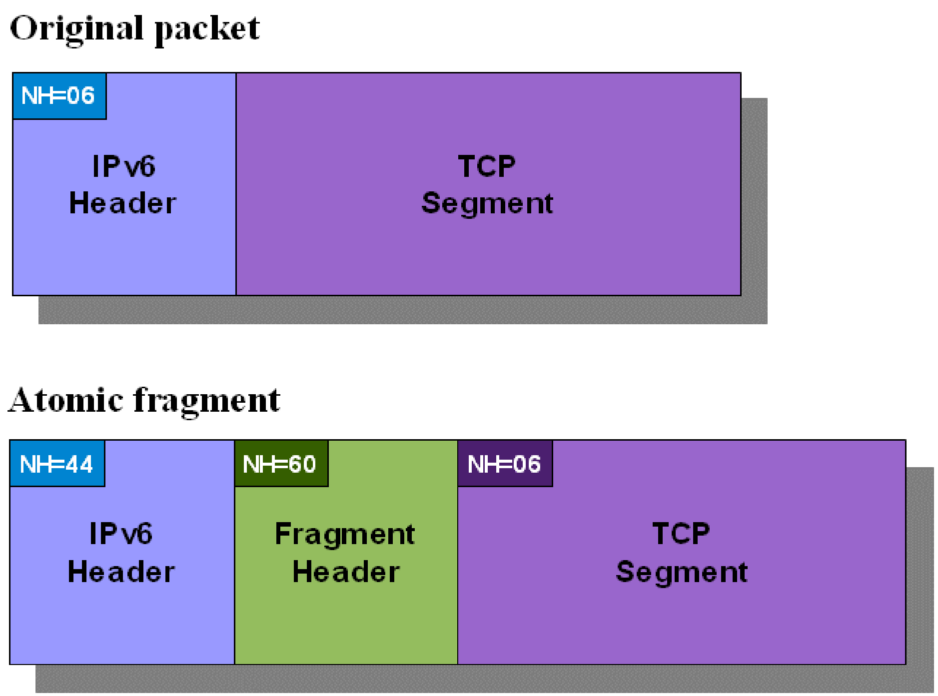
- draft-gont-6man-predictable-fragment-id:
  - Discussed the security implications of predictable Fragment ID
  - Proposes a number of algorithms to generate the Fragment ID
- Ongoing work at the 6man wg
  - Has ot yet been adopted by the 6man working group

# IPv6 Fragment Reassembly

- Security implications of overlapping fragments well-known (think Ptacek & Newsham, etc,)
- Nonsensical for IPv6, but originally allowed in the specs
- Different implementations allow them, with different results
- RFC 5722 updated the specs, forbidding overlapping fragments
- Most current implementations reflect the updated standard
- See http://blog.si6networks.com

# IPv6 “atomic” fragments

- ICMPv6 PTB < 1280 triggers inclusion of a FH in all packets to that destination (not actual fragmentation)
- Result: IPv6 atomic fragments (Frag. Offset=0, More Frag.=0)



# Issues with IPv6 atomic fragments

- Some implementations mix “atomic fragments” with queued fragments
- Atomic fragments thus become subject of IPv6 fragmentation attacks
- How to leverage this issue:
  - Trigger atomic fragments with ICMPv6 PTB messages
  - Now perform IPv6 fragmentation-based attacks

# Mitigating issues with atomic fragments

- draft-ietf-6man-ipv6-atomic-fragments fixes the problem:
  - IPv6 atomic fragments required to be processed as non-fragmented traffic
- Document has passed WGLC
  - Should be published as an RFC soon

# Handling of IPv6 atomic fragments

| Operating System | Atomic Frag. Support | Improved processing |
|---|---|---|
| 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 Vista (build 6000) | Yes | No |
| Windows 7 Home Premium | Yes | No |

At least OpenBSD and NetBSD patched in response to our IETF I-D – more patches expected!

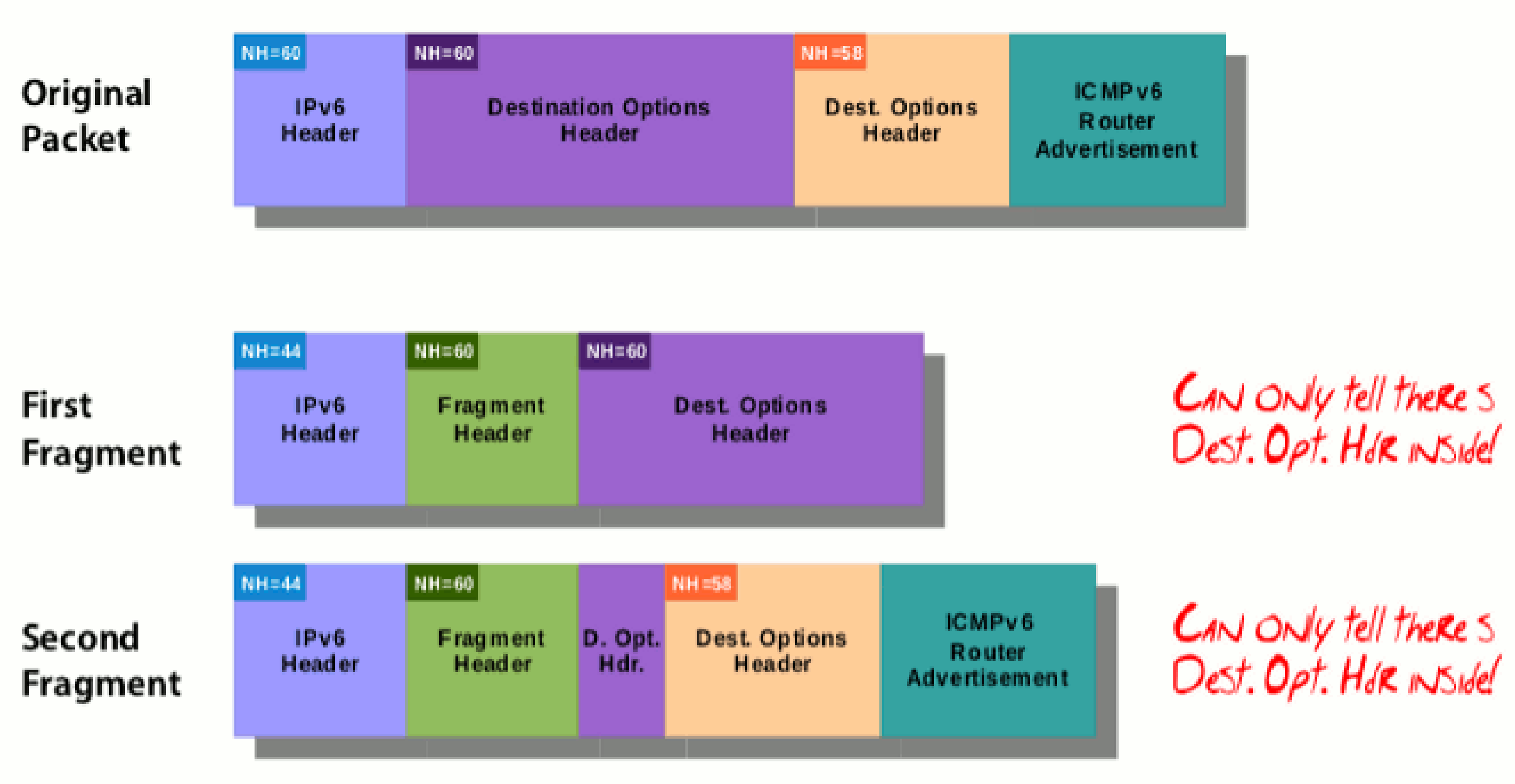
# IPv6 First Hop Security

# IPv6 First Hop Security

- Security mechanisms/policies employed/enforced at the first hop (local network)
- Fundamental problem: lack of feature-parity with IPv4
  - arpwatch-like Neighbor Discovery monitoring virtually impossible
  - DHCP-snooping-like RA blocking trivial to circumvent

# IPv6 First Hop Security (II)

- Fundamental problem: complexity of traffic to be "processed at layer-2"
- Example:



# Bringing “sanity” to ND traffic

- draft-ietf-6man-nd-extension-headers forbids use of fragmentation with Neighbor Discovery
  - It makes ND monitoring feasible
  - Turns out it is vital for SEND (or SEND could be DoS'ed with fragments)
- Work in progress:
  - Has been adopted as a 6man wg item
  - Should be published as an RFC “shortly”

# RA-Guard

- Meant to block RA packets on “unauthorized” switch ports
- Existing implementations trivial to circumvent
- draft-ietf-v6ops-ra-guard-implementation contains:
  - Discussion of RA-Guard evasion techniques
  - Advice to filter RAs, while avoiding false positives
- Can only be evaded with overlapping fragments
  - But most current OSes forbid them
  - And anyway there's nothing we can do about this :-)
- Should be published as an RFC soon.

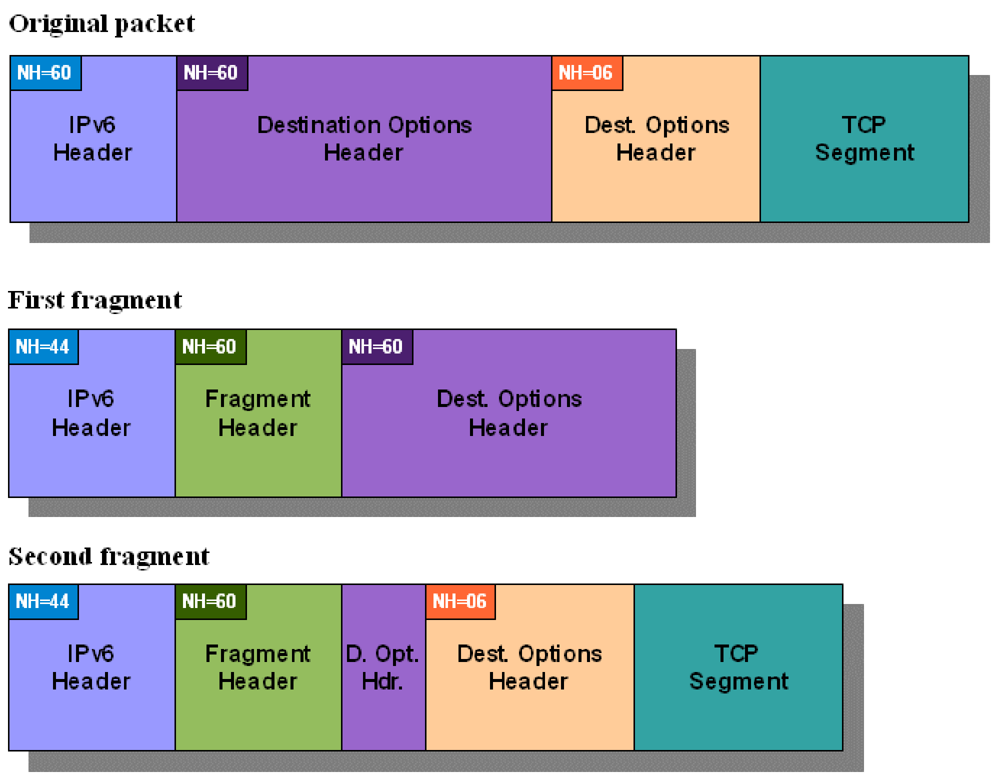


SI6 NETWORKS

# IPv6 firewalling

# Problem statement

- Specs-wise, state-less IPv6 packet filtering is impossible:
  - The IPv6 header chain can span multiple fragments
  - This makes state-less firewalling impossible



# First step away from “insanity”

- draft-ietf-6man-oversized-header-chain fixes this problem:
  - The entire IPv6 header chain must be contained in the first fragment
  - i.e. packets with header chains that span more than one fragment may be blocked – don't send them!
- Work in progress:
  - Already adopted by the 6man WG
  - Should be published as an RFC “shortly”
- There's an insanely large amount of work to be done in the area of IPv6 firewalling

# IPv6 implications on IPv4 networks

# VPN leakages

- Typical scenario:
  - You connect to an insecure network
  - You establish a VPN with your home/office
  - **Your VPN software does not support IPv6**
- Trivial to trigger a VPN leakage
  - Spoof RA's or DHCPv6-server packets, to trigger IPv6 connectivity and set the recursive DNS server
  - Forge DNS responses for servers that are not dual stacked
  - Even legitimate dual-stacked networks may trigger this leakage inadvertently
- As always, deemed as “already known” by some
  - Yet most VPN clients are vulnerable, and nobody did anything about it

# Tools

# IPv6 security tools

- For ages, THC's IPv6 attack suite (http://www.thc.org) has been the only IPv6 security toolkit publicly available
- We've produced "SI6 Networks IPv6 toolkit":
  - A brand-new security assessment/trouble-shooting toolkit
  - Runs on Linux, *BSD, and Mac OS
- Available at: http://www.si6networks.com/tools/ipv6toolkit
  - GIT repository at: https://github.com/fgont/ipv6-toolkit.git

# SI6 Networks' IPv6 toolkit

- scan6: An IPv6 address scanner
- frag6: Play with IPv6 fragments
- tcp6: Play with IPv6-based TCP segments
- ns6: Play with Neighbor Solicitation messages
- na6: Play with Neighbor Advertisement messages
- rs6: Play with Router Solicitation messages
- ra6: Play with Router Advertisement messages

# SI6 Networks' IPv6 toolkit (II)

- rd6: Play with Redirect messages
- icmp6: Play with ICMPv6 error messages
- ni6: Play with Node Information messages
- flow6: Play with the IPv6 Flow Label
- jumbo6: Play with IPv6 Jumbograms
- … and there are more tools to come!

# Some conclusions

# Some conclusions

- Many IPv4 vulnerabilities have been re-implemented in IPv6
  - We just didn't learn the lesson from IPv4, or,
  - Different people working in IPv6 than working in IPv4, or,
  - The specs could make implementation more straightforward, or,
  - **All of the above?** :-)
- Still lots of work to be done in IPv6 security
  - We all know that there is room for improvements
  - **We need IPv6, and should work to improve it**

# Questions?

# Thanks!

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**IPv6 Hackers mailing-list**

**http://www.si6networks.com/community/**

**www.si6networks.com**