Security Implications of the Internet Protocol version 6 (IPv6)

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Agenda

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- Brief comparision of IPv4 and IPv6
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- Address Resolution
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Ongoing work on IPv6 security at UK CPNI

(or “what we’re doing on v6 security”)

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, I’d like to hear from you

Brief Comparision of IPv4 & IPv6

(or “what the small differences are”)

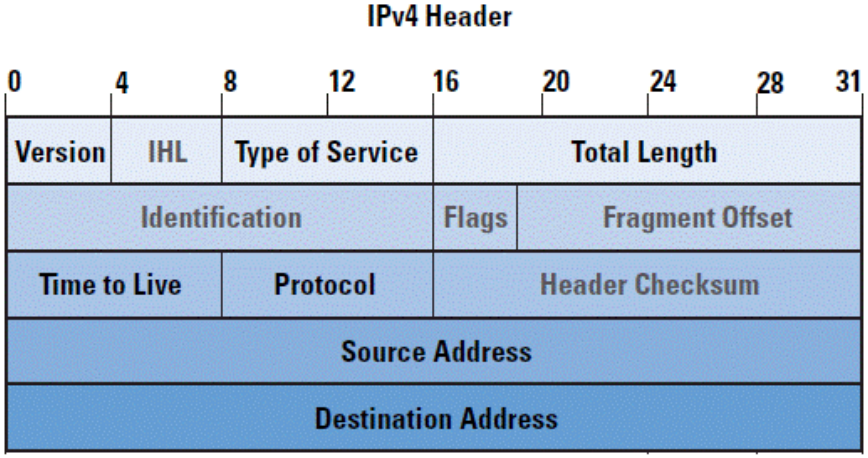
Brief comparision of IPv4 and IPv6 (I)

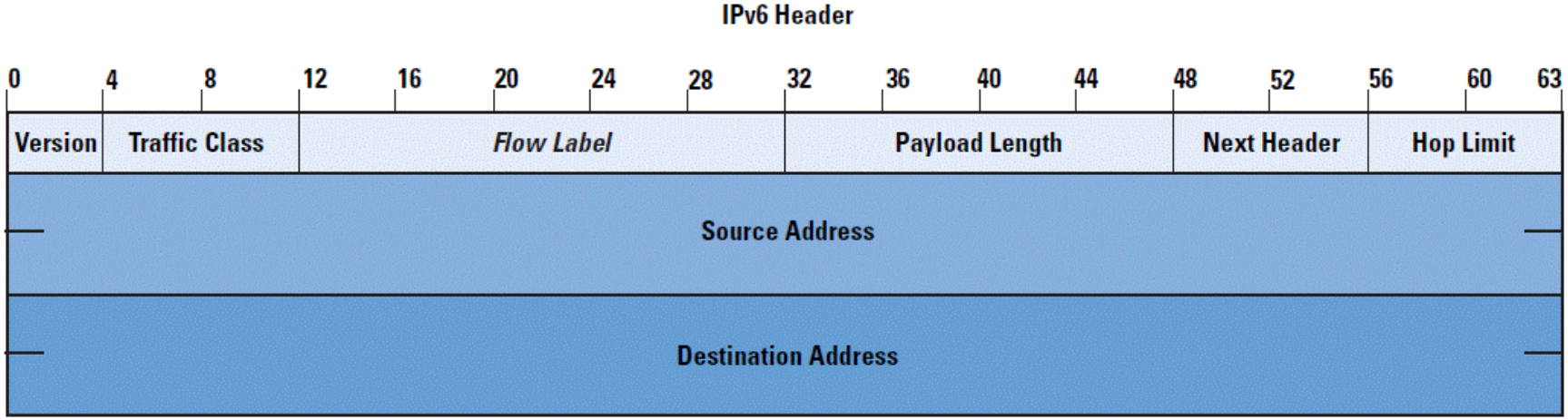
- IPv4 and IPv6 are very similar in terms of functionality

	IPv4	IPv6
Addressing	32 bits	128 bits
Auto-configuration	DHCP & RS/RA	ICMPv6 RS/RA & DHCPv6 (opt)
Address resolution	ARP	ICMPv6
IPsec support	Optional	Mandatory
Fragmentation	Both in hosts and routers	Only in hosts

Brief comparision of IPv4 and IPv6 (II)

- Header formats:





IPv6 addressing

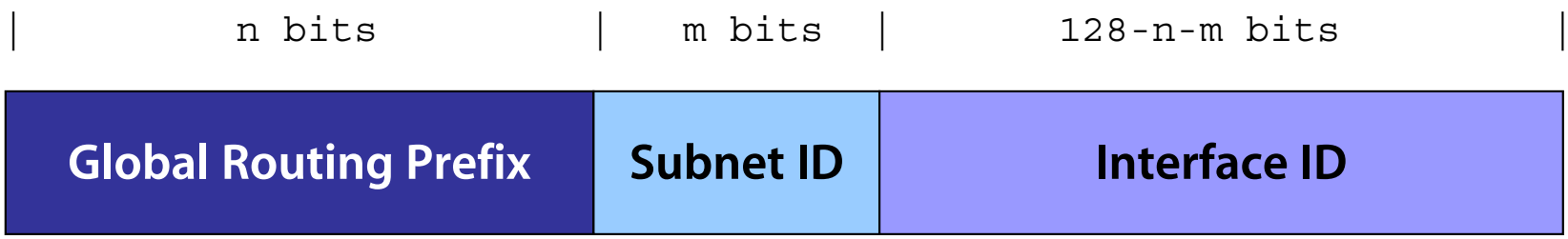
(or “the actual motivator for IPv6”)

Types of IPv6 addresses

- Unicast addresses
  - Identify a single interface
  - Packets are delivered to a single interface
- Multicast addresses:
  - Identify a set of interfaces
  - Packets are delivered to that set of interfaces
- Anycast addresses
  - Identify a set of interfaces
  - Packets are delivered to one interface of the aforementioned set
  - Syntactically indistiguishable from Unicast Addresses
- IPv6 has a Scoped Address Architecture, e.g., it supports:
  - Link-local addresses
  - Global addresses

Global unicast addresses

- Address format:



- The Interface ID is typically 64 bits
- When stateless autoconfiguration is used for network interfaces that have Ethernet Addresses, the Interface ID is set to a value derived from that address (modified EUI-64 format)

Global addresses & Reconnaissance

Myth: "*It is unfeasible to brute-force scan an IPv6 network for alive nodes, as the IPv6 address space is so large. Such a scan would take ages!*"

- [Malone, 2008] (*) measured IPv6 address assignement patterns
- For hosts,
  - 50% autoconf, 20% IPv4-based, 10% Teredo, 8% "low-byte"
- For infrastructure,
  - 70% "low-byte", 5% IPv4-based
- Anyway, think about compromised hosts (e.g., botnets): once a host is compromised, brute-force scanning becomes trivial (sniffing, etc.)

Size matters… only if you use it properly! ;-)

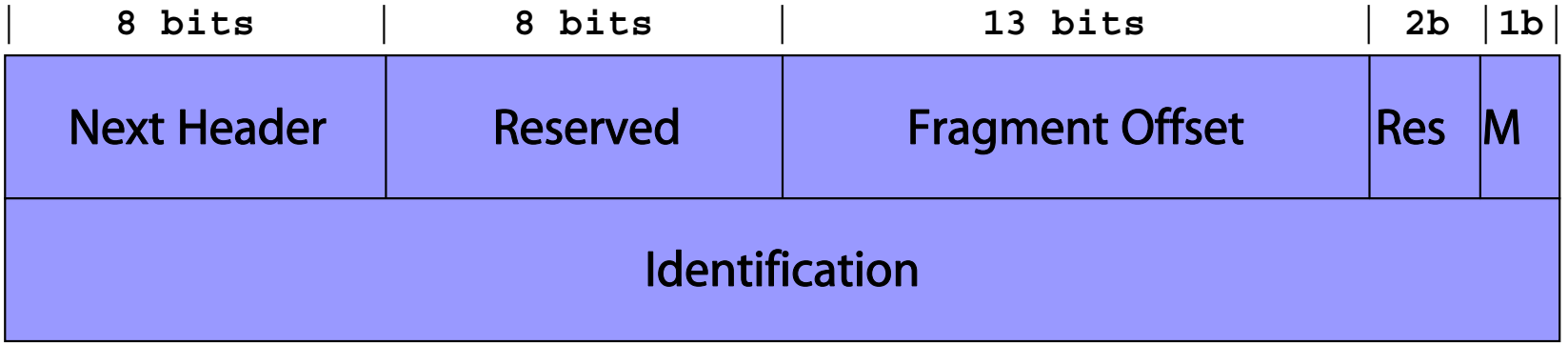
(*) Malone, D. 2008. *Observations of IPv6 Addresses*. Passive and Active Measurement Conference (PAM 2008, LNCS 4979), 29–30 April 2008.

Fragmentation and Reassembly

(or “what we’re doing on v6 security”)

Fragmentation & Reassembly

- The fixed IPv6 header does not include support for fragmentation/reassembly
- If needed, such support is added by an Extension Header (Fragmentation Header)



- Fragment Offset: offset of the data following this header, relative to the start of the fragmentable part of the original packet
- M: “More Fragments” bit, as in the IPv4 header
- Identification: together with the Source Address and Destination Address identifies fragments that correspond to the same packet

Security Implications of IPv6 fragmentation

- Some are the same as for IPv4 fragmentation:
  - Stateful operation for a stateless protocol: risk of exhausting kernel memory!
- Others are different:
  - The Identification field is much larger: chances of “IP ID collisions” are reduced
  - Not all packets carry an “Identification” number: hence it does not leak information so easily (e.g., think about “dumb scan”, etc.)
  - Overlapping fragments have been recently forbidden (RFC 5722) – although it’s unclear the benefits of this.

sysctl's for frag/reassembly

- `net.inet6.ip6.maxfragpackets`: maximum number of fragmented packets the node will accept (defaults to 200 in OpenBSD and 2160 in FreeBSD)
  - 0: the node does not accept fragmented traffic
  - -1: there's no limit on the number of fragmented packets
- `net.inet6.ip6.maxfrags`: maximum number of fragments the node will accept (defaults to 200 in OpenBSD and 2160 in FreeBSD)
  - 0: the node will not accept any fragments
  - -1: there is no limit on the number of fragments

ICMPv6

(or “Internet Control Protocol version 6”)

Internet Control Message Protocol version 6

- ICMP is a core protocol of the IPv6 suite, and is used for:
  - Fault isolation (ICMPv6 errors)
  - Troubleshooting (ICMPv6 echo request/response)
  - Address Resolution
  - Stateless address autoconfiguration
- Contrary to ICMPv4, ICMPv6 is mandatory for IPv6 operation

Fault Isolation (ICMPv6 error messages)

- A number of ICMPv6 error messages are specified in RFC 4443:
  - Destination Unreachable
    - No route to destination
    - Beyond scope of source address
    - Port Unreachable, etc.
  - Packet Too Big
  - Time Exceeded
    - Hop Limit Exceeded in Transit
    - Fragment reassembly time exceeded
  - Parameter Problem
    - Erroneous header field encountered
    - Unrecognized Nect Header type encountered
    - Unrecognized IPv6 option encountered
- Clearly, most of them parallel their ICMP counter-parts

ICMPv6 hard errors

- Some implementation could potentially extrapolate the concept of ICMP(v4) hard errors to ICMPv6 errors (for connections in the synchronized states)
- BSD-derived implementations don't – Good! ;-)

ICMPv6 Packet Too Big

- ICMPv6 PTB messages are used for Path-MTU discovery
- The security implications of these messages are well-known (remember draft-ietf-tcpm-icmp-attacks back in 2004?)
- The mitigations are straightforward:
  - Check the embedded TCP SEQ and, even better, do not honor the ICMP PTB if there's progress on the connection (see draft-ietf-tcpm-icmp-attacks)
- Anyway, the MTU should not be reduced to a value less than 1280. If a smaller MTU is reported, the receiving node is just required to include a frag header.
- sysctl's (OpenBSD)
  - `net.inet6.icmp6.mtudisc_hiwat` (defaults to 1280): Maximum number of routes created in response to ICMP PTBs
  - `net.inet6.icmp6.mtudisc_lowat` (defaults to 256): Maximum number of routes created in response to (unverified) ICMP PTBs

ICMPv6 redirects

- ICMP redirects are very similar to the ICMP counterpart, except for:
  - The Hop Limit is required to be 255
- ICMPv6 redirects are an optimization – hence they can be disabled with no interoperability implications
- Whether ICMPv6 are accepted is controlled in *BSD's with the sysctl `net.inet6.icmp6.rediraccept`. In OpenBSD, it defaults to 1 (**on**).

Node Information Query/Response

- Specified in RFC 4620 as “Experimental”, but included (and enabled by default) in KAME
- Allows nodes to request certain network information about a node in a server-less environment
  - Queries are sent with a target name or address (IPv4 or IPv6)
  - Queried information may include: node name, IPv4 addresses, or IPv6 addresses
- Node Information Queries can be sent with the ping6 command (“-a” and “-b” options)

Node Information Query/Response (II)

- Response to Node Information Queries is controlled by the sysctl `net.inet6.icmp6.nodeinfo`:
  - 0: Do not respond to Node Information queries
  - 1: Respond to FQDN queries (e.g., “ping6 –w”)
  - 2: Respond to node addresses queries (e.g., “ping6 –a”)
  - 3: Respond to all queries
- `net.inet6.icmp6.nodeinfo` defaults to 1 in OpenBSD, and to 3 in FreeBSD.
- My take: unless you really need your nodes to support Node Information messages, disable it (i.e., “sysctl –w net.inet6.icmp6-nodeinfo=0).

Address Resolution

(or “mapping from IPv6 to link-layer”)

Address Resolution

- Employs the Neighbor Discovery Protocol (ICMPv6)
- Every node maintains a “Neighbor Cache”, which contains the mappings from IPv6 address to link-layer address, and the state (e.g., REACHABLE, STALE, etc.) of each entry.
- A node creates an entry in the Neighbor Cache for the target address (in the INCOMPLETE state), and sends a Neighbor Solicitation to the corresponding Solicited-node multicast address
- The target node responds with a Neighbor Advertisement that includes its link layer address
- The node stores the link layer address information in the corresponding Neighbor Cache Entry, and marks the entry as Reachable.
- Reachability information for Neighbor Cache entries is updated based on feedback received from the upper layer, or as a result of “probe” packets

Some Address Resolution games

- Neighbor Cache Poisoning attacks – the v6 version of V4's ARP cache poisoning
  - The attacker simply listens to Neighbor Solicitations for Target addresses he is interested in, and responds with Neighbor Advertisements that contain his own link-layer address
- Advertising "special" link-layer addresses, e.g.,
  - The broadcast Ethernet address (ff:ff:ff:ff:ff:ff)
  - Multicast Ethernet addresses (e.g., 33:33:00:00:01)
  - The link-layer address of the node sending the Neighbor Solicitation – this introduces a forwarding loop if the victim is a router!
  - All BSD variants tested don't check for these special addresses!
- Not much support in layer-2 security boxes to mitigate these attacks
- Open source tools do exist. E.g., NDPMon, available at: http://ndpmon.sourceforge.net

sysctl's for Neighbor Discovery (OpenBSD)

- `net.inet6.ip6.neighborgcthresh` (defaults to 2048): Maximum number of entries in the Neighbor Cache
- `net.inet6.icmp6.nd6_prune` (defaults to 1): Interval between Neighbor Cache babysitting (in seconds).
- `net.inet6.icmp6.nd6_delay` (defaults to 5): specifies the DELAY_FIRST_PROBE_TIME constant from RFC 4861.
- `net.inet6.icmp6.nd6_umaxtries` (defaults to 3): specifies the MAX_UNICAST_SOLICIT constant from RFC 4861
- `net.inet6.icmp6.nd6_mmaxtries` (defaults to 3): specifies the MAX_MULTICAST_SOLICIT constant from RFC 4861.
- `net.inet6.icmp6.nd6_useloopback` (defaults to 1): If non-zero, uses the loopback interface for local traffic.
- `net.inet6.icmp6.nd6_maxnudhint` (defaults to 0): Maximum number of upper-layer reachability hints before normal ND is performed.

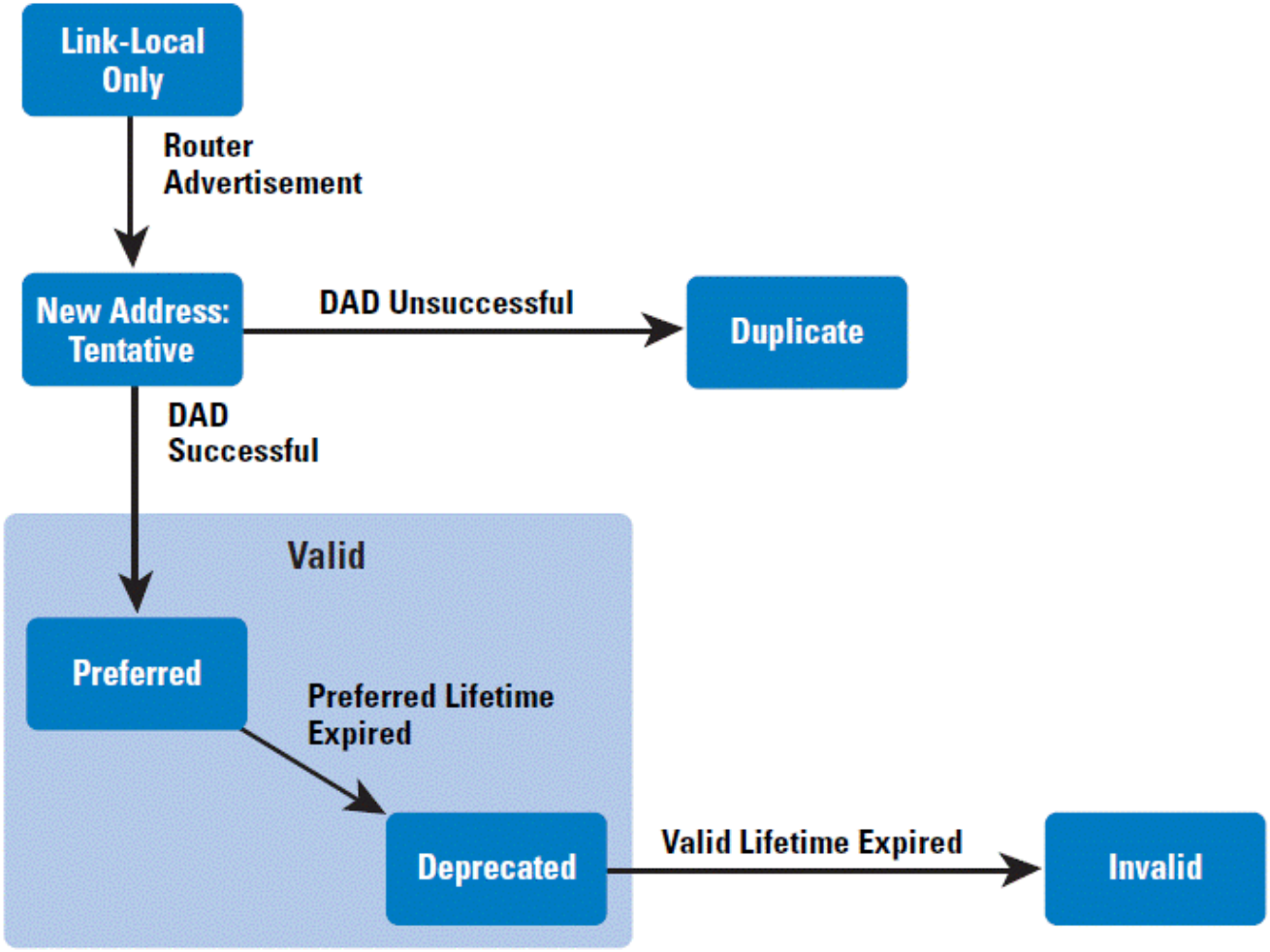
Stateless address autoconfiguration

(or “what we’re doing on v6 security”)

Auto-configuration

- Employs the Neighbor Discovery Protocol (ICMPv6 messages) – DHCPv6 is optional.
- Basic autoconfiguration
  - The node sends a multicast Router Solicitation message to the “all-routers”
  - Routers respond with prefixes for autoconfiguration
  - The node configures its own IPv6 address(es) with the advertised prefixes, plus a locally-generated Interface ID
  - Checks whether the selected address(es) are unique (Duplicate Address Detection)
  - If unique, the address is configured.

Address autoconfiguration flowchart



Other autoconf information

- Source Link-Layer Address option: advertises the link-layer address of the sender
- Prefix Information option: advertises “on-link” prefixes, and prefixes to be used for stateless address autoconfiguration.
- Route Information Option: Advertises “more specific routes”.
- Recursive DNS Server option: Advertises a “caching” DNS server
- MTU option: Advertises the MTU to be used for this link

Some address autoconf games

- Rogue router: an attacker could send solicited/unsolicited Router Advertisements:
  - Advertise itself as a default router
  - Advertise bogus prefixes for on-link determination/autoconfiguration
  - Advertise more specific routes through his malicious node
  - Impersonate another router and cause victim nodes to remove it from their routing table
- Exploiting Duplicate Address Detection
  - Simply respond to all Neighbor Solicitations that are part of the DAD, and cause address autoconfiguration to fail
- Some (not all) of this vulnerabilities can be exploited with THC's "IPv6 attack suite"

sysctl's for autoconf (OpenBSD)

- `net.inet6.ip6.accept_rtadv` (defaults to 1): Controls whether Router Advertisements are accepted.
- `net.inet6.ip6.dad_count` (defaults to 1): Number of DAD probes sent when an interface is first brought up
- `net.inet6.ip6.maxifprefixes` (defaults to 16): Maximum number of prefixes per interface.
- `net.inet6.ip6.maxifdefrouters` (defaults to 16): maximum number fo default routers per interface.

Autoconf addresses & Privacy

- Addresses selected as part of stateless autoconfiguration contain a modified version of the MAC address of the interface
- The MAC address is globally-unique, and non-changing (OUI assigned by the IEEE to the vendor, plus a 3-byte number selected by the vendor)
- There were concerns that autoconf addresses hurt privacy, as they could be used to correlate network activity
- Privacy addresses (RFC 4941) were introduced for that purpose
  - They basically set the Interface ID to a random number, and are short
  - They are short-lived
  - They tend to be painful for the purpose of logging

sysctl's for Privacy Addresses

- Privacy extensions for autoconf is implemented in FreeBSD (but not in, e.g., OpenBSD)
- These sysctl's control their operation:
  - `net.inet6.ip6.use_tempaddr` (defaults to 0)
    - Controls whether Privacy addresses are configured
  - `net.inet6.ip6.temppltime` (defaults to 86400)
    - Specifies the "preferred lifetime" for privacy addresses
  - `net.inet6.ip6.tempvltime` (defaults to 604800)
    - Specifies the "valid lifetime" for privacy addresses
  - `net.inet6.ip6.prefer_tempaddr` (defaults to 0)
    - Controls whether privacy addresses are "preferred" (i.e., whether outgoing "conections" should use privacy addresses)

Personal rant on IPv6 security

(or “what’s missing in the IPv6 arena?”)

Key areas in which further work is needed

- IPv6 Resiliency
  - Implementations have not really been the target of attackers, yet
  - Only a handful of publicly available attack tools
  - Lots of vulnerabilities and bugs still to be discovered.
- IPv6 support in security devices
  - IPv6 transport is not broadly supported in security devices (firewalls, IDS/IPS, etc.)
  - This is key to be able enforce security policies comparable with the IPv4 counterparts
- Education/Training
  - Pushing people to "Enable IPv6" *point-and-click style* is simply **insane**.
  - Training is needed for engineers, technicians, security personnel, etc., **before** the IPv6 network is running.

Questions?

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