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Network 1st Hop Security

Mitigating the security risks of ARP, DHCP and IPv6 Autoconfiguration

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WP8-T1

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Public

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The First Hop

- The way from the end-system (PC, Laptop, Server, Tablet, etc.) to the default router
- Aka the local (W)LAN segment
  - One collision domain for all systems on the local net: Hubs, shared coaxial cabling (very old), access point (WLAN)
  - One collsion domain per end-system: VLAN with one or more switches
- Additionally: Locally active servers for network infrastrcture
  - DHCP
  - Optionally: TFTP, DNS, others

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Local network: Attack Surface

- Detection of other hosts on the subnet: ARP, IPv6 NDP
  - Obtaining the MAC address for a given IP address to communicate locally
  - Without the MAC address of the default gateway, no communication beyond local network
- Automatic configuration of IP addresses: DHCP, IPv6 SLAAC
  - This usually includes the IP address of the default gateway (router)
- Other end-system configuration: DHCP (IPv4 & IPv6)
  - DNS server, NTP server, (Windows) Domain Controllers
- Not covered
  - Directly accessible services on switches, access points or routers (SSH, Web, etc.)
  - Other servers on the local network

ARP Basics

- **ARP**: **A**ddress **R**esolution **P**rotocol (RFC 826)
  - Host wants to find the link-layer (MAC) address for a (destination) IP-address
- How:
  - Host broadcasts (MAC address ff:ff:ff:fff:ff:ff) ARP request
  - If a host with this IP address is on the local link, it responds with its IP address in an Ethernet frame (unicast to the querying host)
  - Learned address pairs (IP, MAC) are stored locally in the ARP cache
  - Cache will be updated when a host receives ARP responses, even if already present
  - Hosts may send unsolicited ARP responses (i.e. in case of address changes)
- ARP can be used for duplicate address detection (RFC 5227)
  - Requests with empty source address and (tentative) IP address

ARP Attacks

- ARP Spoofing: Sending of fake ARP responses
- ARP (Cache) Poisoning: Planting false entries into a victims ARP cache through ARP Spoofing
- Allows Man-in-the-Middle (MitM) attacks: reading or alterting (unencrypted) traffic through impersonating the legitimate communication partner
  - Usually the default gateway, proxy, etc.
  - Impersonating DNS server or DHCP server allows further MitM attacks

ARP Attack Detection

- Watch for deviating entries in the ARP cache
- Deviating: IP-MAC address pair is not what it is supposed to be
  - Esp. default gateway, DNS/DHCP servers, proxies, etc.
- CLI: **`arp -an`** (old) or **`ip neighbor show`** (newer)
- Better: Monitoring tools: addrwatch, ArpON, arpwatch
  - One host per LAN segment is enough due to ARP ethernet broadcasts
  - The segment may contain several IP subnets
  - Alerting through Syslog or E-mail
- Monitoring switch table of (MAC, port, VLAN) mappings (CAM)
  - Gives also a hint to where the attack might come from (switch ports)

ARP Attack Mitigation

- Static ARP cache entries
  - I.e. manually configuring IP-MAC pairs on each host
  - Impractical on larger networks
- Locking down MAC addresses on switch ports
  - Works against ARP spoofing only when triplet (MAC, IP, port) is monitored/protected
  - Manual configuration or auto-learning through DHCP traffic monitoring
  - Reconfiguration required when systems move, HW changes, etc.
- Encrypting/authenticating traffic end-to-end with certificates
  - Alerts/aborts communication when certificates do not match
  - How do users know a certficiate is faked?

DHCP: Basics

- **DHCP**: **D**ynamic **H**ost **C**onfiguration **P**rotocol (RFC 2131)
- How it works: “DORA”
  - Client sends (DHCP) **D**iscover Message
  - Server answers with (DHCP) **O**ffer Message
  - Client chooses from the offers, sends (DHCP) **R**equest message
  - Server sends (DHCP) **A**cknowledgement message with configuration parameters
    - IP address, MTU, TTL, DNS server, NTP server, Domain controller, etc.
- Implemented on top of (older) BootP protocol
  - Server: Port 67/udp
  - Client: Port 68/udp

DHCP: Attacks

- Rogue DHCP client
  - Attacker client assigns all IP addresses to himself → Denial-of-Service by address pool exhaustion
  - Not such a big problem with IPv6 – really?
- Rogue DHCP server
  - Attacker masquerades as the (legitimate) DHCP server
  - Can send his own configuration parameters to clients
  - Means for further attacks: MitM, eavesdropping, modifying traffic
- DHCP Spoofing
  - Attacker sends forged DHCP responses
  - Consequences similar to rogue DHCP server

DHCP Attack Detection

- Monitor DHCP messages (DHCP snooping)
  - Unusually large number of Discover or Request packets
    - ⇒ perhaps a misconfigured or rogue DHCP client
  - DHCP Offer/Acknowledgements not coming from legitimate (IP, MAC) address pairs
    - ⇒ sign of rogue DHCP servers or DHCP spoofing
- Monitor DHCP server logs
  - Handing out unusually large number of leases
  - Requests for strange options (those not usually asked for by clients)

DHCP Attack Mitigation

- Filtering of DHCP Offer/Acknowledgements (DHCP Guard)
  - Those that come from switch ports other than that of the legitimate server
  - The other part of DHCP Snooping
  - Filter DHCP at the network boundary firewall
  - If not using DHCP relays, filter at the subnet boundary
- DHCP authentication (RFC 3118)
  - Servers with support available (Cisco, Juniper, ISC, …)
  - Client support not yet there?
  - <u>**All**</u> clients on the (local) net have to support it

DHCPv6

- Different protocol (RFC 8415)
  - Now implemented directly on UDP(v6)
  - Client port: 546/udp
  - Server port: 547/udp
- Operational principle is the same as in DHCP on IPv4
  - DISCOVER, OFFER, REQUEST, ACKNOWLEDGE messages
- Security software has to work with different protocol and port numbers

IPv6

- Yes, you have it on your local (sub)network - although it might not work beyond the first hop
- It’s build-in and enabled by default on all operating systems
  - Linux, *BSD, Windows, MacOSX, etc. since 15 years at least!

```
> ip addr show dev wlan0
3: wlan0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc mq state UP group default
qlen 1000
    link/ether dc:8b:28:5b:79:a3 brd ff:ff:ff:ff:ff:ff
    inet 192.168.93.99/24 brd 192.168.178.255 scope global noprefixroute dynamic wlan0
       valid_lft 841369sec preferred_lft 841369sec
    inet6 fe80::f742:11d7:4008:159a/64 scope link noprefixroute
       valid_lft forever preferred_lft forever
> ping ff02::1%wlan0
PING ff02::1%wlan0(ff02::1%wlan0) 56 data bytes
64 bytes from fe80::f742:11d7:4008:159a%wlan0: icmp_seq=1 ttl=64 time=0.022 ms
64 bytes from fe80::9ec7:a6ff:fe25:eff1%wlan0: icmp_seq=1 ttl=64 time=2.63 ms (DUP!)
64 bytes from fe80::4240:a7ff:feb6:49fc%wlan0: icmp_seq=1 ttl=255 time=163 ms (DUP!)
```

IPv6 Address configuration

- Three ways to configure IPv6 addresses
  - Static (manually)
  - Stateless Address Autoconfiguration (SLAAC)
  - Stateful (DHCPv6)
- Really just choosing the Interface ID (last 64 bit)
- Prefix (first 64 bit) usually given
  - Statically by network admin, automatically by router/DHCPv6 server
- Problems
  - Differences between/and co-existance of IPv4 and IPv6
  - Privacy issues with IPv6 interface IDs

IPv6 Stateless Address Auto Configuration (SLAAC)

- Process, by which IPv6 hosts obtain
  - (Global) IPv6 Prefix
  - Interface ID
  - Router (default gateway) IP address
  - DNS server IP address
  - Check if their (choosen) IP address is not already in use on the subnet
- IPv6 Neighbor Discovery Protocol (RFC 4861)
- Implemented in five ICMPv6 message types
  - Router Solicitation (Type 133)
  - Router Advertisement (Type 134)
  - Neighbor Solicitation (Type 135)
  - Neighbor Advertisement (Type 136)
  - Redirect (Type 137)

IPv6 Neighbor Discovery

- Neighbor Solicitation/Advertisemens
  - Host A wants to send data to host B (in the local subnet)
  - A knows Bs IPv6 address but not the link-layer address
  - A sends Neighbor Solicitation packet the multicast MAC address B is regsitered at (can be deducted from B's IPv6 address)
  - B answers with Neighbor Advertisement Packet to A's Unicast MAC address (knows it from the Neighbor Solicitation message)
  - This packet includes B's MAC-Address
  - A and B communicate via Unicast from here on
- This mechanism replaces (IPv4) ARP!

IPv6 Duplicate Address Detection

- Host A wants to know if the IPv6 address choosen is already in use in the subnet
- A sends Neighbor Solicitation Packet to the multicast address of the choosen IPv6 address (source address is ::)
- If the address is already in use, the using host sends a Neighbor Advertisement packet to the link-local all-nodes multicast address (ff02::1)
- If A receives no answer, the address can be used

IPv6 Router Discovery

- Router periodically sends Router Advertisements (RA)
  - Unsolicited: semi-periodically from router to link-local all-nodes address (ff02::1)
  - Solicited: as answer to Router Solicitation (RS) packet from a host
- Host extracts
  - List of valid (subnet)prefixes for this subnet
  - If a prefix can be used for SLAAC or not
  - List of routers (default gateways)
  - Lifetime of the RA
  - Hop Limit
  - Optional parameters like MTU or DNS servers

IPv6 SLAAC Process

- Host creates a link-local IPv6 address (State: **tentative**)
- Hosts uses DAD to check if the address is unique
  - If already in use: STOP!
  - Else: IP address enters state **valid**
- Host sends Router Solicitation
- Host received Router Advertisement(s)
  - If no RA received, continue with DHCPv6
  - If prefix can be used for SLAAC, create global IPv6 address
- Check global address with DAD
  - If unique (no answer), enter state Valid
  - If not unique, continue with next prefix
  - No more prefixes? STOP!

ND Attacks

- ND spoofing
  - For each Neighbor Solicitation packet, send a (fake) Neighbor Advertisement
    - DAD/SLAAC stops → Denial of Service
  - Send out lots of fake Neighbor Advertisements
    - Overflow of Neighbor tables in systems on the local network

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RA Attacks

- RA spoofing (aka Rogue IPv6 Router)
  - Attacker sends fake RA packets
    - Removes existing routers from routing table
    - Can assign fake prefixes to hosts on the subnet
    - Makes his/her router the default gateway → MitM attacks
  - Can turn an IPv4 only net into a dual stack network!
- **IPv6 is preferred by default over IPv4!**

NDP Attack Detection

- Monitoring of IPv6 address – MAC address pairs: addrwatch
  - Like arpwatch, but includes IPv6
- Monitor routing/neighbor tables at local hosts
  - Sudden increase is likely a sign of attack → HIDS
- Snooping of ICMPv6 at the switch
  - Catches both ND and RA attacks and probably more

NDP Attack Mitigations

- Filtering of RAs on the switch ports (Router Guard)
  - Can be bypassed with IPv6 Extension Headers if BCP not followed
- Static configuration of IPv6 addresses (disable RA processing)
  - Ignore ICMPv6 types 133, 134, 137 completely
  - Resolves most RA issues at the price of considerable more work
  - And shuts down DHCPv6 also:(
- Set router preference flag (RFC 4191) to “high” on your routers
  - Only a minor help
- Authentication of ND and RA packets (SEND)
  - Not used/supported

DHCPv6 and SLAAC

- Usage of DHCPv6 is dependant on flags in RAs
  - Managed Configuration Flag (M): Use a ***Configuration Protocol*** (i.e. DHCP) to obtain an IPv6 address (stateful)
  - Other Stateful Configuration Flag (O): Use a ***Configuration Protocol*** to get further informations (i.e. DNS servers, etc.)

M	O	Meaning
0	0	Don‘t use DHCPv6
0	1	Use DHCPv6 only for further information (DHCP Stateless)
1	0	Use DHCPv6 only to obtain an IPv6-Adress
1	1	Use DHCPv6 for both IPv6 Adress and further information

Mitigation: One Size doesn't fit all

Zone	Rogue RA Mitigation Measure	cost (+ o -)	feasibility	effect (+ o -)
Internal Network	Router-Preference=high / Monitor NDP Managed Switch (RA Guard, Port ACLs)	+/-	+	0/+
Internal Server-Zone	Router-Preference=high / Monitor NDP Disable RA processing	+	+	+
DMZ	Router-Preference=high / Monitor NDP Disable RA processing	+	+	+
Guestnet Wired	Router-Preference=high Managed Switch with RA Guard or Port ACLs	-	+	+
Guestnet Wireless	Router-Preference=high Partitioning	+/o	+	+

Original slide(s): https://www.first.org/education/ipv6_security.zip

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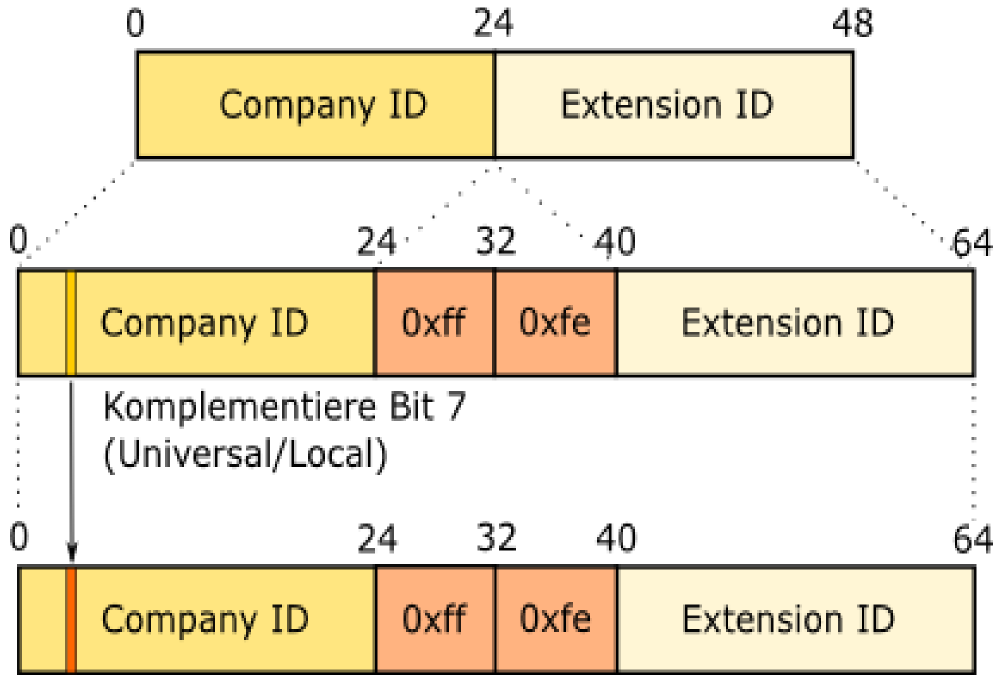
IPv6 Local interface ID

- Two step process
  - Derive EUI-64 from 48 Bit MAC address
  - Complement bit 7

MAC address
say: 00:25:64:df:5d:c7

EUI-64 address
say: 00:25:64:ff:fe:df:5d:c7

IPv6 Interface ID
say: 0225:64ff:fedf:5dc7



Company ID:
http://standards.ieee.org/regauth/oui/oui.txt

IPv6 Interface ID Privacy Problem

- 64 bit is enough to uniquely identify a system (48-bit actually)
- Tracking possible across different subnets (work, home, cafe, …)
- Solution: Privacy Enhancements (RFC 4941)
- Randomly choosen Interface ID with regular changes aka *temporary address*
- However
  - Default interval is often too long → allows tracking again
    - Router Advertising and Kernel variables
  - And it’s not changed when the prefix changes
  - An EUI-64 (public) address may be assigned additionally, preference?
    - Controlled by kernel variables on Linux/*BSD

What you have learned?

- Basic Overview of attacks on ARP, IPv6 NDP and DHCP(v6)
- Basic Mitigation measures

What has been left out?

- DNS/mDNS Security: Will be covered in an upcoming course on DNS Security
- LAN protocols: STP, VTP, LLDP, CDP, etc.: Turn it off on links to end-systems
- Router failover protocols: HSRP, VRRP, etc.

Thank you

Any questions?

Next module: ***Authentication***, 13th of August 2020

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- A. Pilihanto: “A Complete Guide on IPv6 Attack and Defense”, SANS 2011, `https://www.sans.org/reading-room/whitepapers/detection/complete-guide-ipv6-attack-defense-33904`
- J. Davies “Understanding IPv6”, 3rd Ed., Microsoft Press, 2012, ISBN-13: 978-0735659148
- R. Droms, T. Lemon “The DHCP Handbook”, 2nd Ed. SAMS 2002, ISBN-13: 978-0672323270

Standards

- RFC 826: "An Ethernet Address Resolution Protocol", D. Plummer, November 1982, `https://tools.ietf.org/html/rfc826`
- RFC 2131: "Dynamic Host Configuration Protocol", R. Droms, March 1997, `https://tools.ietf.org/html/rfc2131`
- RFC 3118: "Authentication for DHCP Messages", R. Droms, W. Arbaugh, June 2001, `https://tools.ietf.org/html/rfc3118`
- RFC 3971: "SEcure Neighbor Discovery (SEND)", J. Arkko et al, March 2005, `https://tools.ietf.org/html/rfc3971`
- RFC 4191, "Default Router Preferences and More-Specific Routes",R. Draves, November 2005, `https://tools.ietf.org/html/rfc4191`
- RFC 4861: "Neighbor Discovery for IP version 6 (IPv6)", T. Narten et al, September 2007, `https://tools.ietf.org/html/rfc4861`
- RFC 5227: "IPv4 Address Conflict Detection", S. Cheshire, July 2008, `https://tools.ietf.org/html/rfc5227`
- RFC 8415: "Dynamic Host Configuration Protocol for IPv6 (DHCPv6)", T. Mrugalski et al, November 2018, `https://tools.ietf.org/html/rfc8415`

Tools: Offense

- ARP
  - Arp-scan: `https://github.com/royhills/arp-scan`
  - Ettercap: `https://www.ettercap-project.org/`
- DHCP
  - `DHCPig:https://github.com/kamorin/DHCPig`
  - Dhcpstarv: `http://dhcpstarv.sourceforge.net/`
  - Yersinia: https://sourceforge.net/projects/yersinia/ (old homepage, new homepage broken?)
- IPv6
  - SI6 Networks' IPv6 toolkit: `https://www.si6networks.com/research/tools/ipv6toolkit/`
  - Chiron: `https://github.com/aatlasis/Chiron`
  - THC IPv6 Attack Suite: `https://github.com/vanhauser-thc/thc-ipv6`

Tools: Defense

- ARP
  - Addrwatch: https://github.com/fln/addrwatch
  - Arpwatch: ftp://ftp.ee.lbl.gov/arpwatch.tar.gz
  - TuxCut: https://a-atalla.github.io/tuxcut/
  - ArpON: http://arpon.sourceforge.net/
- DHCP
  - Open DHCP Locate: http://odhcploc.sourceforge.net/
  - Univ. Princeton dhcp_probe: https://www.net.princeton.edu/software/dhcp_probe/
  - Microsoft DHCPLOC Utility: https://gallery.technet.microsoft.com/DHCPLOC-Utility-34262d82
- IPv6
  - Addrwatch: https://github.com/fln/addrwatch

Backup material

Stuff that didn't make it due to time constraints

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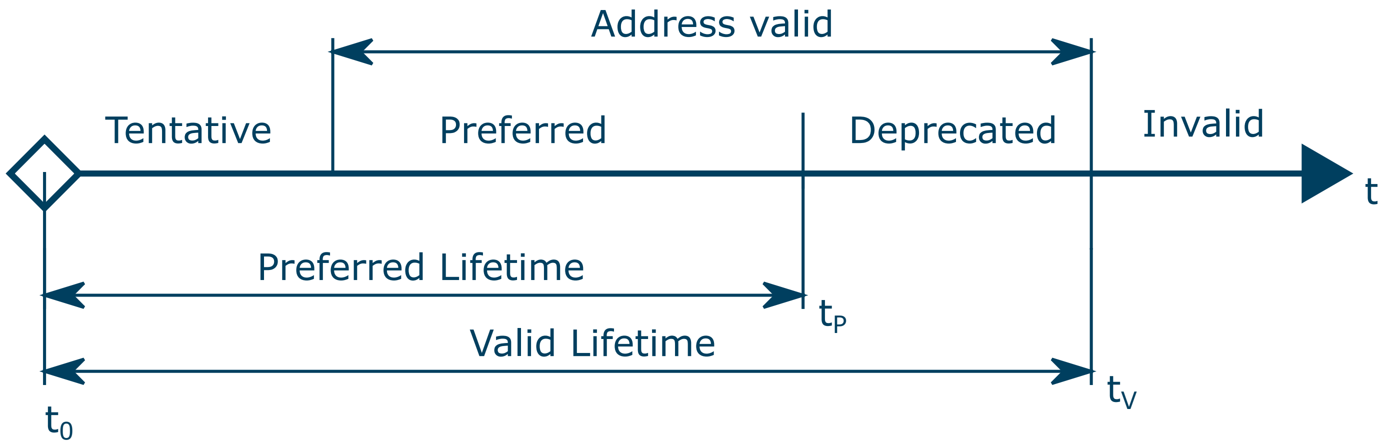
the European Union's Horizon 2020 research and innovation
programme under Grant Agreement No. 731122 (GN4-2).

IPv6 Address configuration

- Static, like IPv4
  - Linux: `ifconfig …` or `ip addr …`
    - Persistent configurations vary (`/etc/…?`)
  - Windows: GUI or `netsh interface …`
- Use for
  - Central servers that better have fixed addresses
  - Administrators responsibility that addresses are unique
- High Security, if
  - Neighbor Advertisements are ignored
  - Router Advertisments are ignored
    - What to do when router fails (VRRP?)

IPv6 Address states

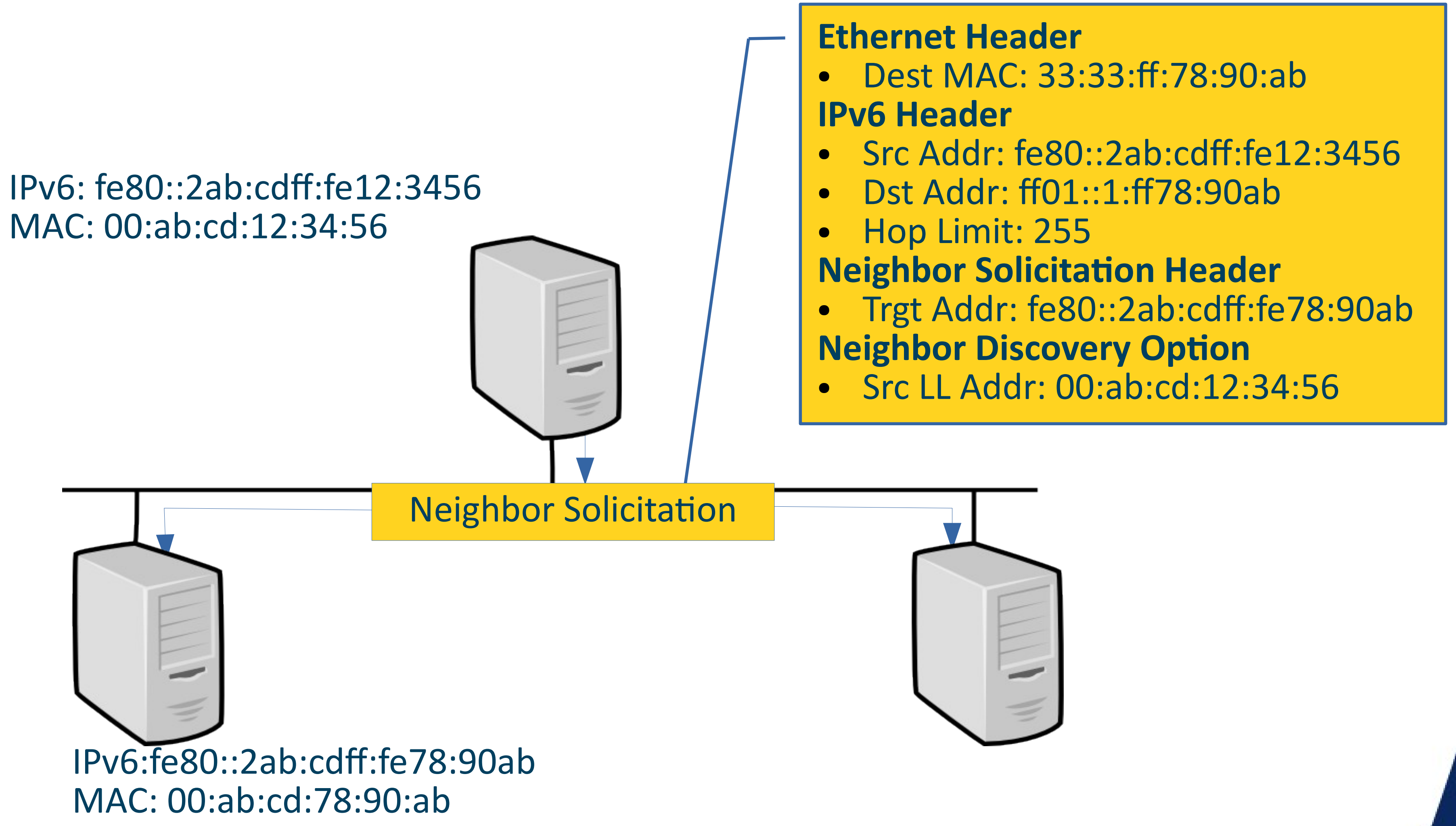
- ***Tentative***: Address is still being checked for uniqueness
- ***Valid***: Address can be used to send and receive
  - Includes Preferred and Deprecated states
- ***Preferred***: Address is preferred for new connections
- ***Deprecated***: Address should not be used for new connections
- ***Invalid***: Address can't be used anymore



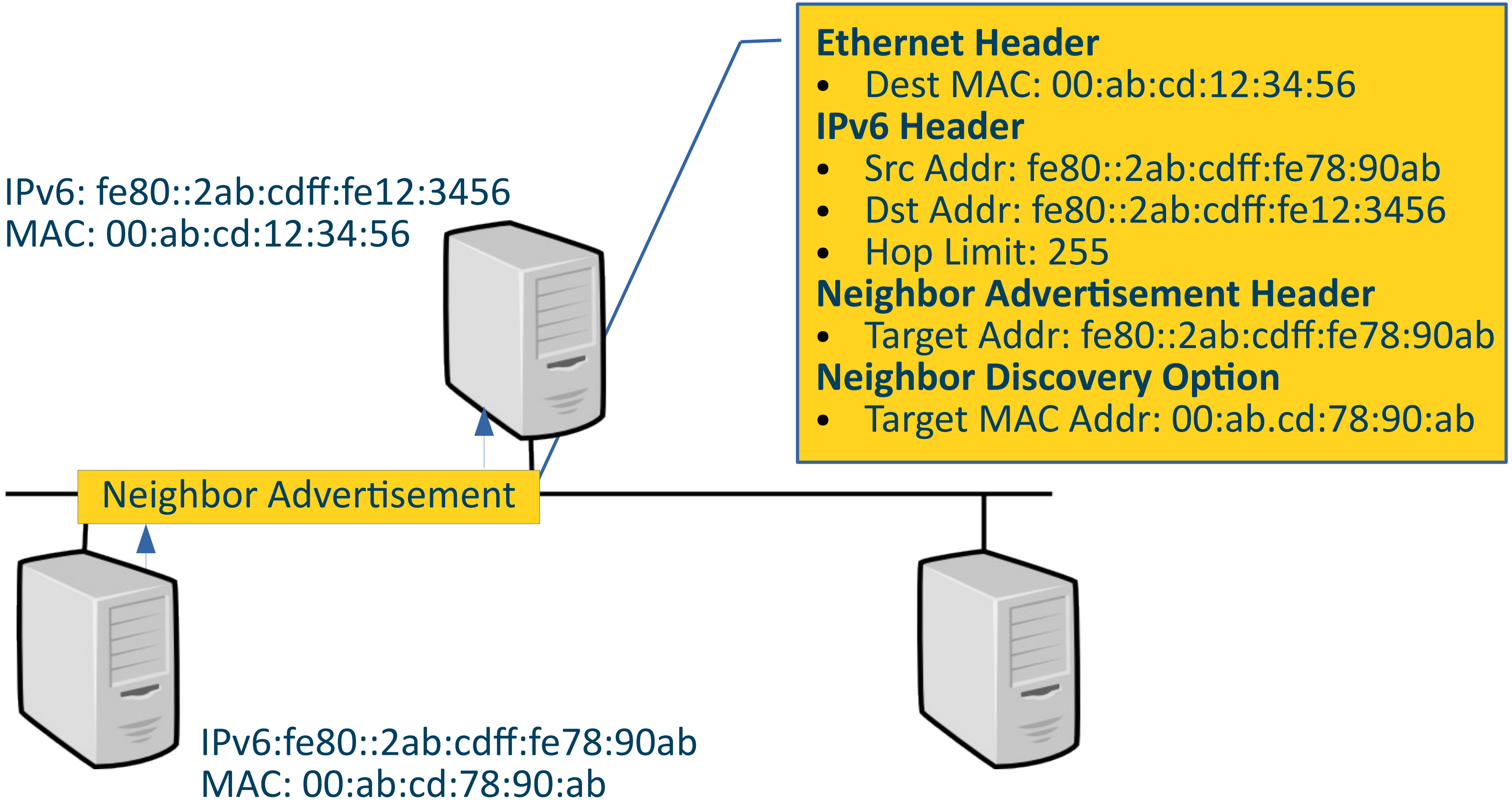
How to enable/disable Privacy Extensions

- Linux
  - `sysctl -w net.ipv6.conf.all.use_tempaddr=2` (Default=0)
  - `Sysctl -w net.ipv6.conf.all.temp_preferred_lft=14400` (Default 86400)
  - Entries in `/etc/sysctl.conf`
- FreeBSD/Mac OS X
  - `sysctl -w net.inet6.ip6.use_tempaddr=1`
  - `sysctl -w net.inet6.ip6.prefer_tempaddr=1`
- MS Windows
  - `netsh interface ipv6 set global randomizeidentifiers=disabled`
  - Default: enabled

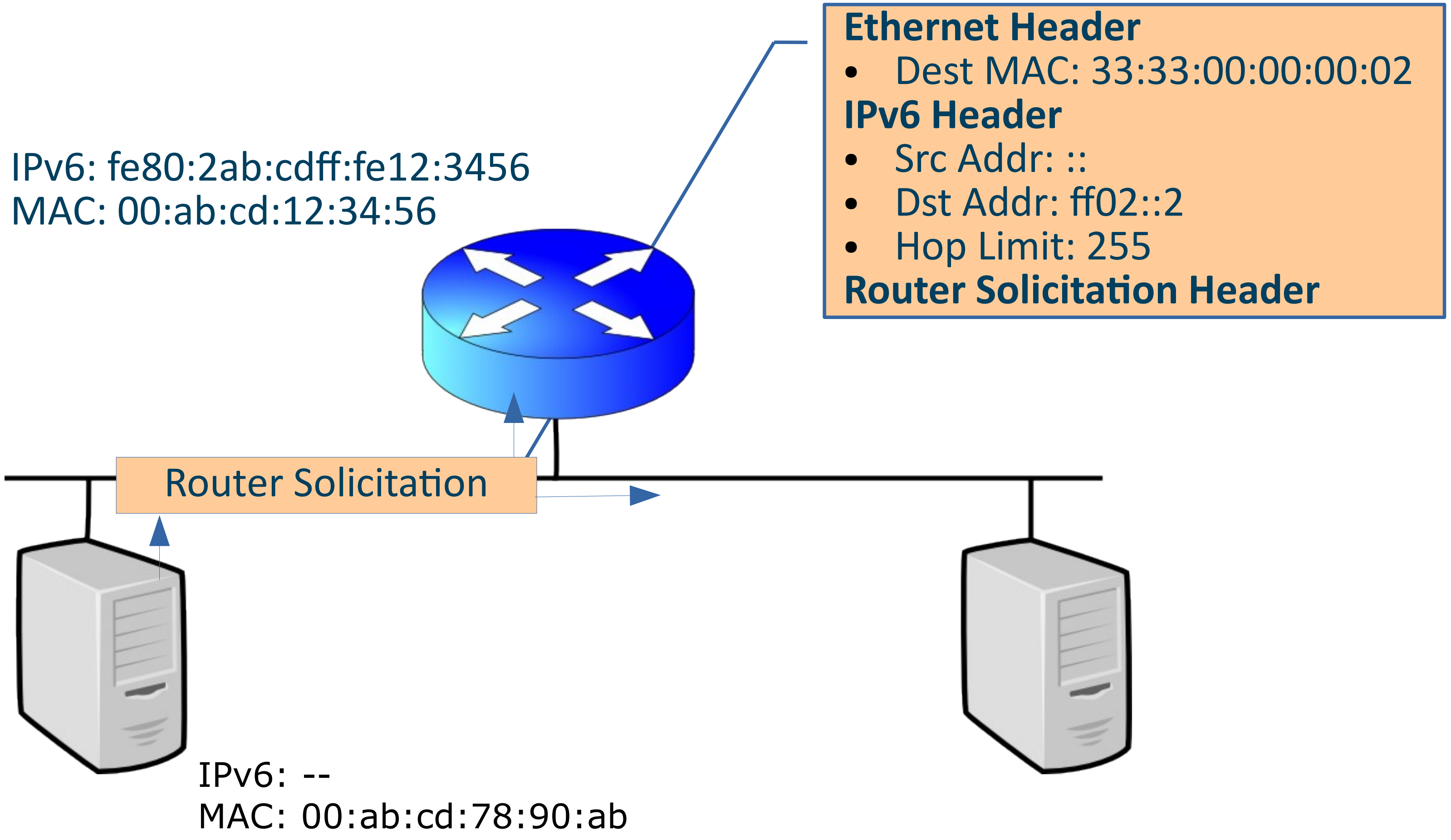
IPv6 Neighbor Solicitation



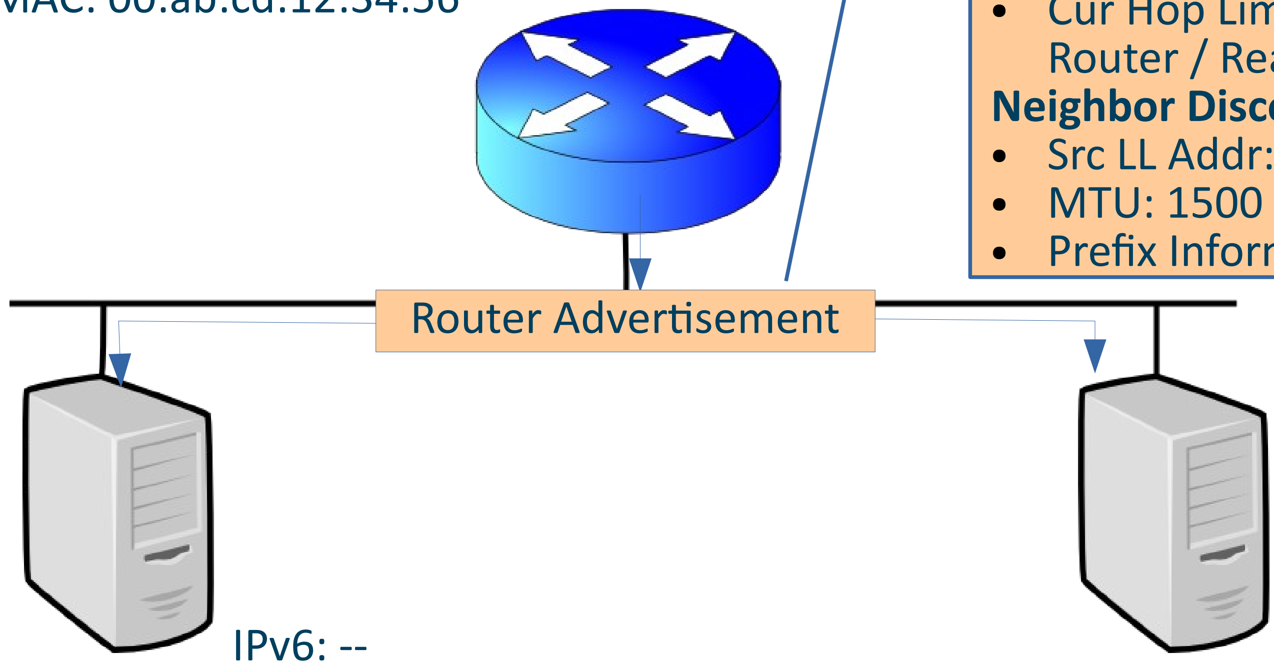
IPv6 Neighbor Advertisement



IPv6 Router Solicitation



IPv6 Router Advertisement



Ethernet Header
- Dest MAC: 33:33:ff:78:90:ab

IPv6 Header
- Src Addr: fe80::2ab:cdff:fe12:3456
- Dst Addr: ff02::1
- Hop Limit: 255

Router Advertisement Header
- Cur Hop Limit, Flags,
  Router / Reachable / Retrans

Neighbor Discovery Option
- Src LL Addr: 00:ab:cd:12:34:56
- MTU: 1500
- Prefix Information

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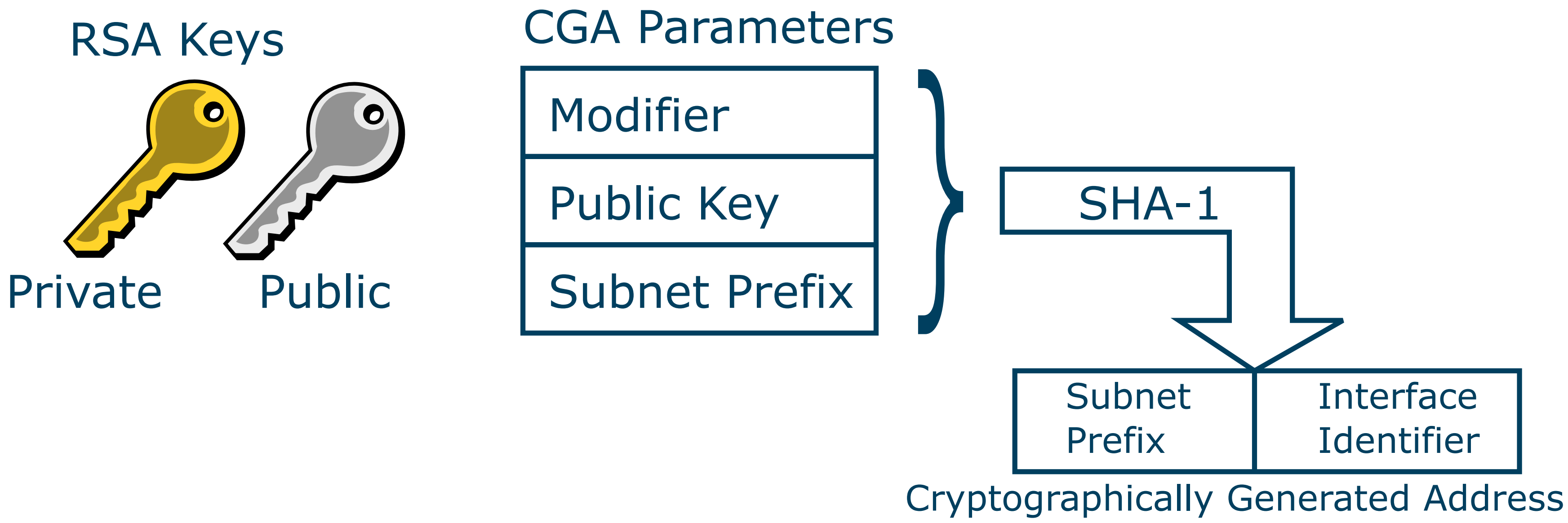
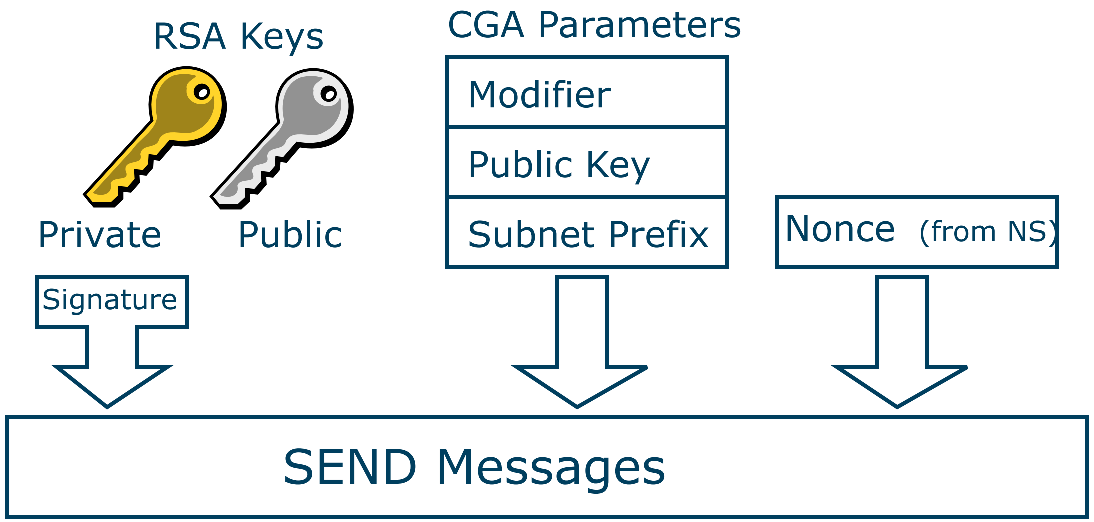
IPv6 Secure Neighbor Discovery (SEND, RFC 3971)

- Host has to prove that an IPv6 address really belongs to it
- Host creates RSA key pair
- Used to generate Cryptographically Generated Address (CGA)
  - Modifier: Random numbers



IPv6 Secure Neighbor Discovery

- Host adds SEND messages as options to Neighbor Adverisements
- “Proof”
  - The CGA address really belongs to the public key
  - The host has this accompanying private key
- For a successful attack, the attacker has to find (in time) a key pair that generates the same signature



IPv6 SEND Problems

- Lack of support in operating systems:
  - None: Windows, MacOS X, BSD
  - Linux kernel patches, but not in mainline
  - Cisco IOS 12.2, Juniper?
- Susceptible to Denial-of-Service attacks
  - Attacker floods local network with SEND NS packets
  - Victims have to to many cryptographical operations (RSA is slow)
- Layer 2 attacks (MAC address spoofing) can still be done