RIPE NCC

RIPE NETWORK COORDINATION CENTRE

IPv6 Security

NOG.HR - Tutorial

October 2023

Overview

- IPv6 Security vs IPv4 Security
- Reachability of IPv6 Addresses
- Network Scanning in IPv6
- Attacks on IPv6
- IPv6 vs IPv4
- IPv6 Support
- IPv4-Only Networks
- IPv6 Security Resources

IPv6 Security Statements

1	2	3	4	5	6	7	8

- IPv6 is **more secure** than IPv4
- IPv6 has better security and it's **built in**

Reason:

- RFC 4294 - IPv6 Node Requirements: IPsec **MUST**

Reality:

- RFC 8504 - IPv6 Node Requirements: IPsec **SHOULD**
- IPsec available. Used for security in IPv6 protocols

Reality

A change of mindset is necessary

- IPv6 is not more or less secure than IPv4
- Knowledge of the protocol is the best security measure

For a Good Level of Security

1	Best security tool is knowledge
2	IPv6 security is a moving target
3	IPv6 is happening: need to know about IPv6 security
4	Cybersecurity challenge: Scalability IPv6 is also responsible for Internet growth

IPv6 Security Statements

1	**2**	3	4	5	6	7	8

- IPv6 has no NAT. Global addresses used
- I'm exposed to attacks from Internet

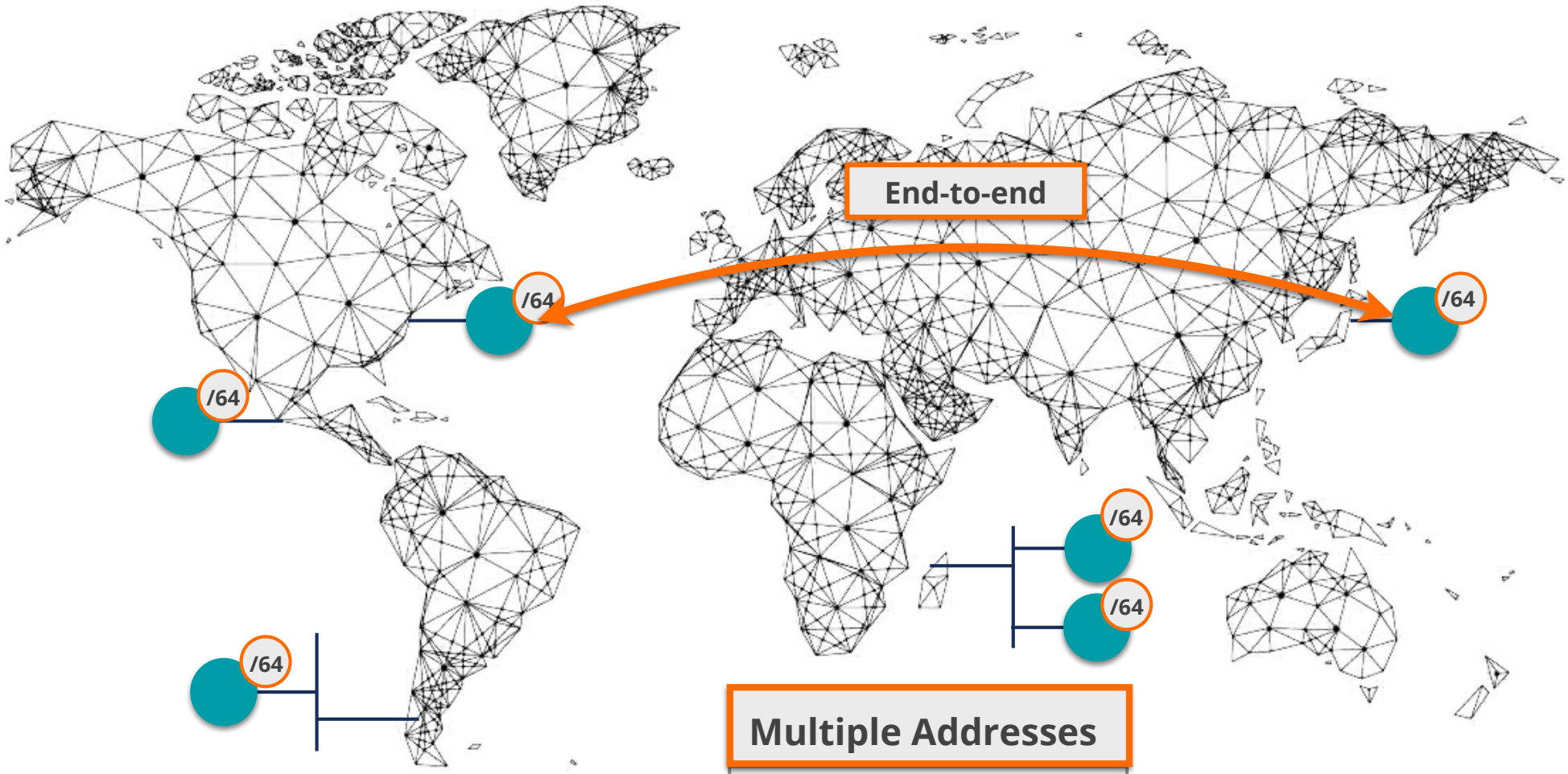
Reason:

- End-2-End paradigm. Global addresses. No NAT

Reality:

- Global addressing does not imply global reachability
- You are responsible for reachability (filtering)

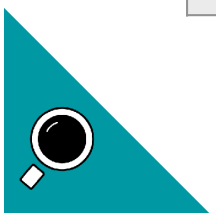
340,282,366,920,938,463,463,374,607,431,768,211,456



Multiple Addresses
Link-local
Global (GUA)
Multicast

Special / Reserved IPv6 Addresses

Name	IPv6 Address	Comments
Unspecified	::/128	When no address available
Loopback	::1/128	For local communications
IPv4-mapped	::ffff:0:0/96	For dual-stack sockets. Add IPv4 address 32 bits
Documentation	2001:db8::/32	RFC 3849
IPv4/IPv6 Translators	64:ff9b::/96	RFC 6052
Discard-Only Address Block	100::/64	RFC 6666
Teredo	2001::/32	IPv6 in IPv4 Encapsulation Transition Mechanism
6to4	2002::/16	IPv6 in IPv4 Encapsulation Transition Mechanism
ORCHID	2001:10::/28	Deprecated RFC 5156
Benchmarking	2001:2::/48	RFC 5180
Link-local	fe80::/10	RFC 4291
Unique-local	fc00::/7	RFC 4193
6Bone	3ffe::/16, 5f00::/8	Deprecated RFC 3701
IPv4-compatible	::/96	Deprecated RFC 5156

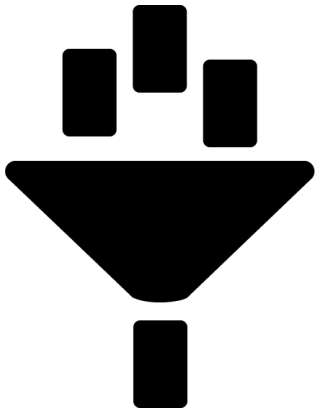


http://www.iana.org/assignments/iana-ipv6-special-registry/

Security Tips

- Use **hard to guess** IIDs
  - RFC 7217 better than Modified EUI-64
  - RFC 8064 establishes RFC 7217 as the default
- Use **IPS/IDS** to detect scanning
- **Filter** packets where appropriate
- Be careful with routing protocols
- Use "default" **/64** size IPv6 subnet prefix

Filtering in IPv6 is very Important!

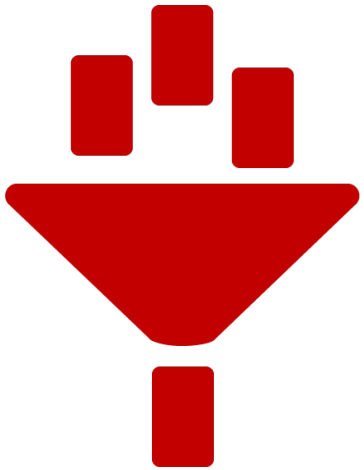


- Global Unicast Addresses
- A good **addressing plan**

Easier filtering!

New Filters to Take Into Account

- ICMPv6
- IPv6 Extension Headers
- Fragments Filtering
- Transition mechanisms (TMs) / Dual-Stack



FILTER ICMPv6 CAREFULLY!

Used in many IPv6 related protocols

ICMPv6 Error Messages

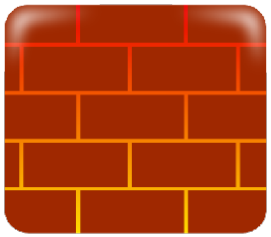
Type	Code
Destination Ureachable (1)	No route to destination (0)
	Communication with destination administratively prohibited (1)
	Beyond scope of source address (2)
	Address Unreachable (3)
	Port Unreachable (4)
	Source address failed ingress/egress policy (5)
	Reject route to destination (6)
	Error in Source Routing Header (7)
Packet Too Big (2) Parameter = next hop MTU	Packet Too Big (0)
Time Exceeded (3)	Hop Limit Exceeded in Transit (0)
	Fragment Reassembly Time Exceeded (1)
Parameter Problem (4) Parameter = offset to error	Erroneous Header Field Encountered (0)
	Unrecognized Next Header Type (1)
	Unrecognized IPv6 Option (2)
	IPv6 First Fragment has incomplete IPv6 Header Chain (3)

Filtering ICMPv6

Type - Code	Description	Action
Type 1 - all	Destination Unreachable	ALLOW
Type 2	Packet Too Big	ALLOW
Type 3 - Code 0	Time Exceeded	ALLOW
Type 4 - Code 0, 1 & 2	Parameter Problem	ALLOW
Type 128	Echo Reply	ALLOW for troubleshoot and services. Rate limit
Type 129	Echo Request	ALLOW for troubleshoot and services. Rate limit
Types 131,132,133, 143	MLD	ALLOW if Multicast or MLD goes through FW
Type 133	Router Solicitation	ALLOW if NDP goes through FW
Type 134	Router Advertisement	ALLOW if NDP goes through FW
Type 135	Neighbour Solicitation	ALLOW if NDP goes through FW
Type 136	Neighbour Advertisement	ALLOW if NDP goes through FW
Type 137	Redirect	NOT ALLOW by default
Type 138	Router Renumbering	NOT ALLOW

More on RFC 4890 - https://tools.ietf.org/html/rfc4890

Filtering Extension Headers



- **Firewalls** should be able to:
  1. Recognise and filter some **EHs** (example: **RH0**)
  2. Follow the **chain of headers**
  3. Not allow **forbidden combinations** of headers

Filtering Fragments

Upper layer info not in 1st fragment	Creates many tiny fragments to go through filtering / detection
Fragments inside fragments	Several fragment headers
Fragmentation inside a tunnel	External header hides fragmentation

Filtering Fragments

Upper layer info not in 1st Fragment	**All header chain should be in the 1st fragment** [RFC7112]
Fragments inside fragments	**Should not happen in IPv6. Filter them**
Fragmentation inside a tunnel	**FW / IPS / IDS should support inspection of encapsulated traffic**

Filtering TMs / Dual-stack

Technology	Filtering Rules
Native IPv6	EtherType 0x86DD
6in4	IP proto 41
6in4 (GRE)	IP proto 47
6in4 (6-UDP-4)	IP proto 17 + IPv6
6to4	IP proto 41
6RD	IP proto 41
ISATAP	IP proto 41
Teredo	UDP Dest Port 3544
Tunnel Broker with TSP	(IP proto 41) || (UDP dst port 3653 || TCP dst port 3653)
AYIYA	UDP dest port 5072 || TCP dest port 5072

More on RFC 7123 - https://tools.ietf.org/html/rfc7123

IANA Protocol Numbers -
https://www.iana.org/assignments/protocol-numbers/protocol-numbers.xhtml

IPv6 Packet Filtering

Much more important in IPv6

+

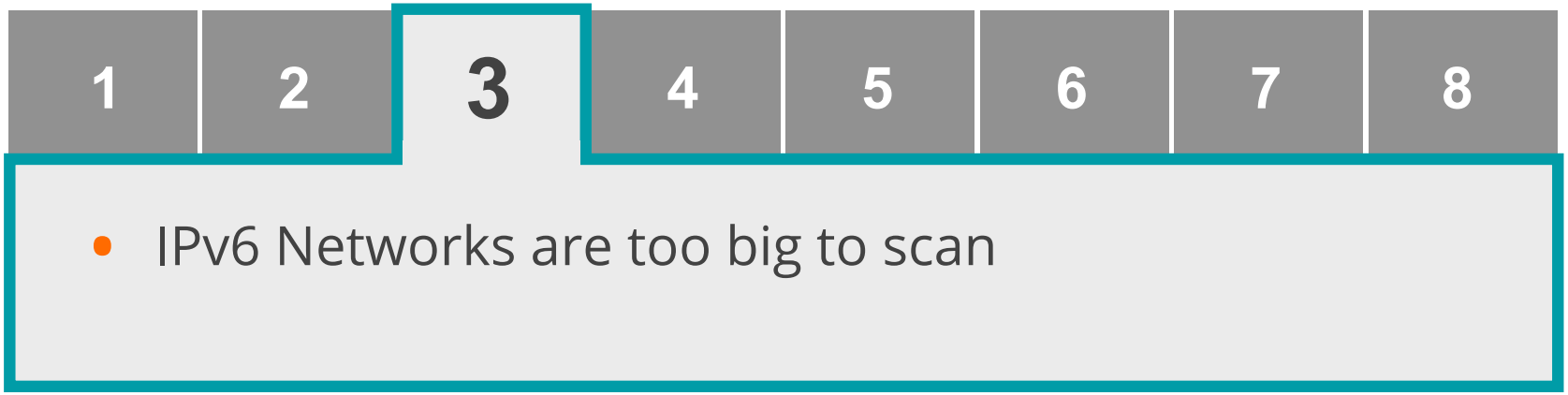
Common IPv4 Practices

+

New IPv6 Considerations

- End to End needs filtering
- ICMPv6 should be wisely filtered
- Filtering adapted to IPv6: EHs, TMs

IPv6 Security Statements



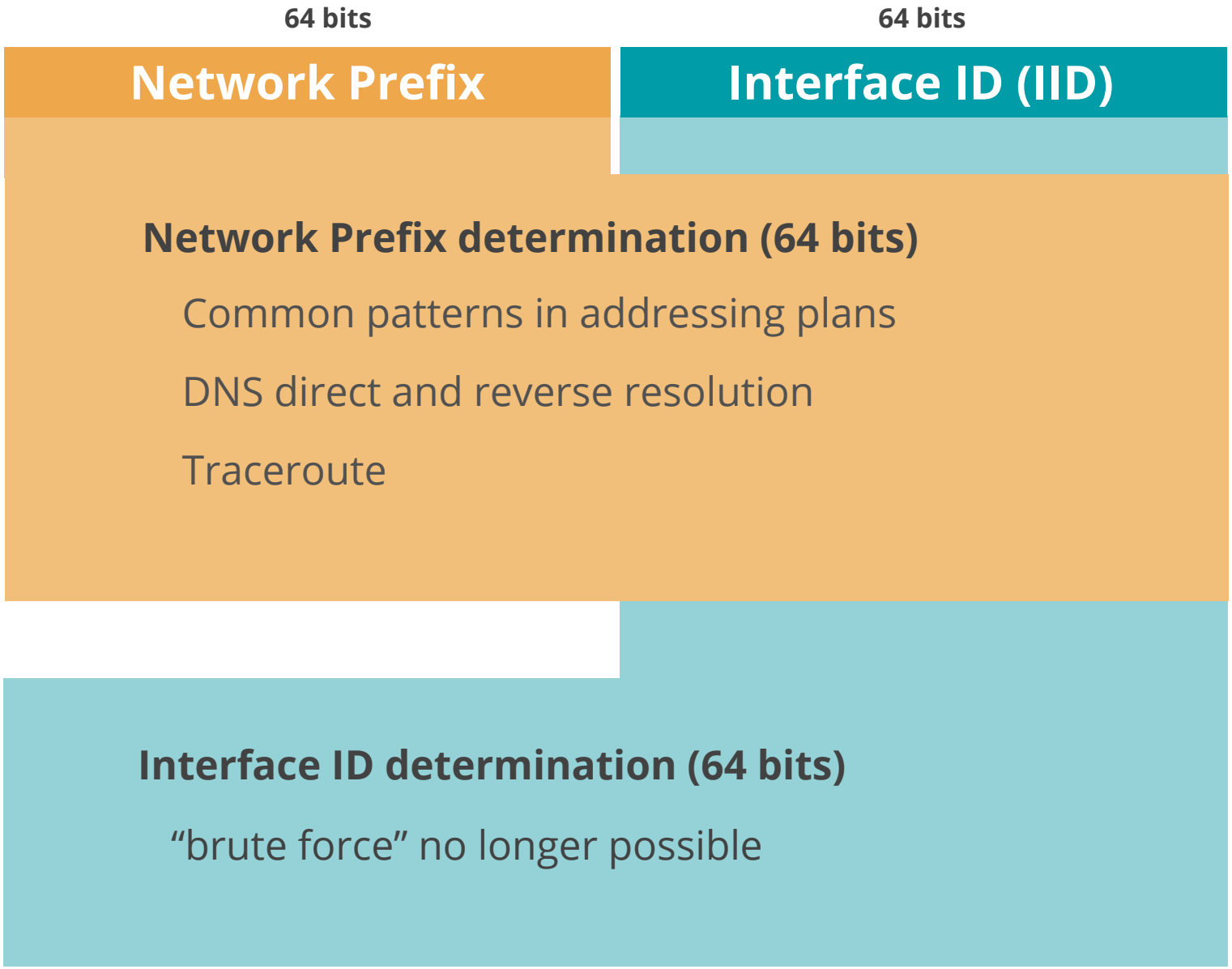
Reason:

- Common LAN/VLAN use /64 network prefix
- 18,446,744,073,709,551,616 hosts

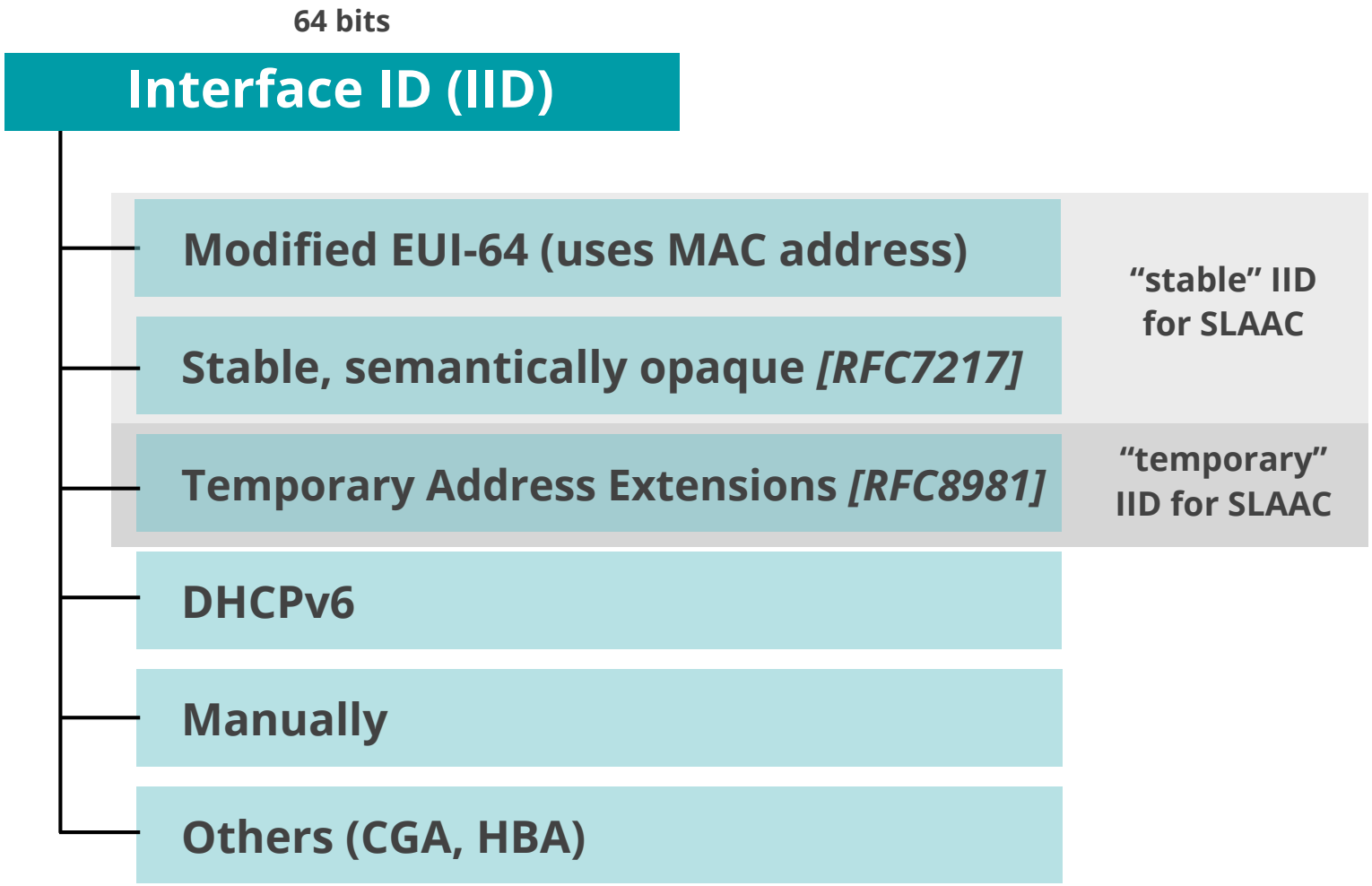
Reality:

- Brute force scanning is not possible [RFC5157]
- New scanning techniques

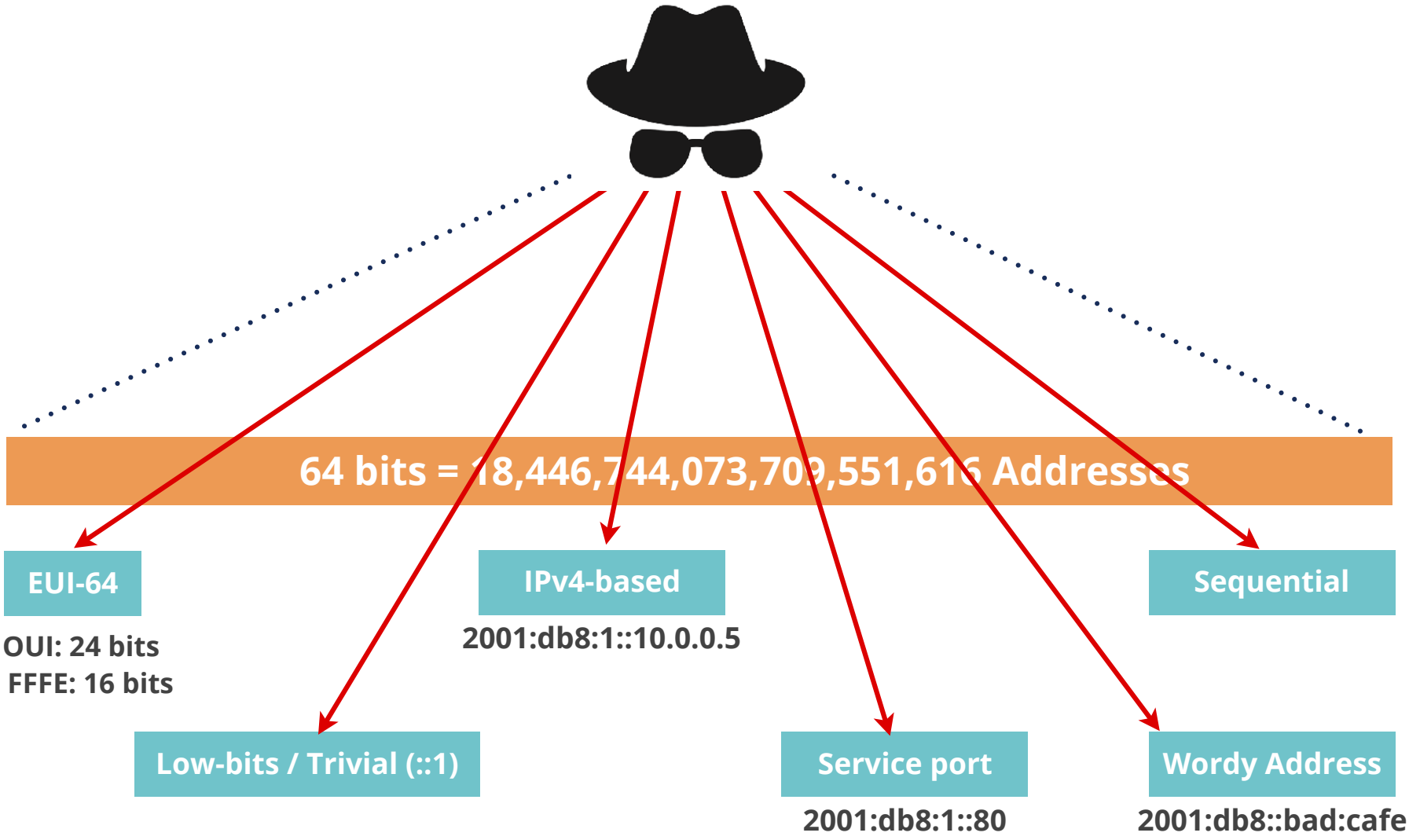
IPv6 Network Scanning



IID Generation Options



Guessing IIDs



IPv6 Security Statements

1	2	3	**4**	5	6	7	8

- IPv6 is too new to be attacked

Reason:

- Lack of knowledge about IPv6 (*it's happening!*)

Reality:

- There are tools, threats, attacks, security patches, etc.
- You have to be prepared for IPv6 attacks

IPv6 is Happening...

RANK	IPV6%	COUNTRY / REGION
1	100%	Bahrain
2	55.7%	Montserrat
3	55.7%	Saudi Arabia
4	54.9%	India
5	53.9%	Uruguay
6	53%	France
7	53%	Malaysia
8	52.1%	Germany
9	50.7%	Greece
10	50.4%	United States
11	50.1%	Puerto Rico
12	50%	Viet Nam
13	48.6%	Belgium
14	46.4%	Japan

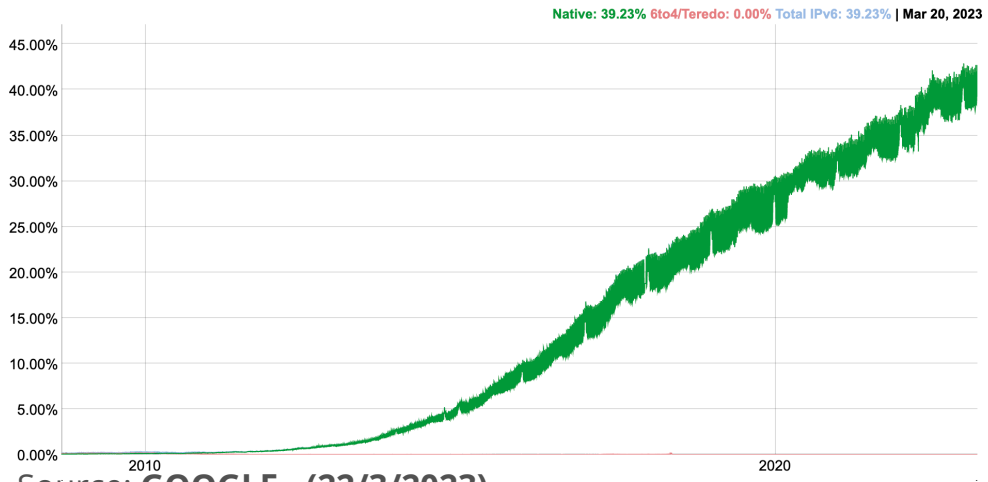
Source: **AKAMAI - (22/3/2023)**

Show 10 entries Search:

Rank	Participating Network	ASN(s)	IPv6 deployment
1	RELIANCE JIO INFOCOMM LTD	55836, 64049	92.58%
2	Comcast	7015, 7016, 7725, 7922, 11025, 13367, 13385, 20214, 21508, 22258, 22909, 33287, 33489, 33490, 33491, 33650, 33651, 33652, 33653, 33654, 33655, 33656, 33657, 33659, 33660, 33661, 33662, 33664, 33665, 33666, 33667, 33668, 36732, 36733	73.62%
3	Combined US Mobile Carriers	3651, 6167, 10507, 20057, 21928, 22394	87.74%
4	Charter Communications	7843, 10796, 11351, 11426, 11427, 12271, 20001, 20115, 33363	56.41%
5	ATT	6389, 7018, 7132	72.32%
6	T-Mobile USA	21928	92.31%
7	Deutsche Telekom AG	3320	74.48%
8	Orange Business Services	3215	74.08%
9	Verizon Wireless	6167, 22394	83.58%
10	Claro Brasil	4230, 28573	74.53%

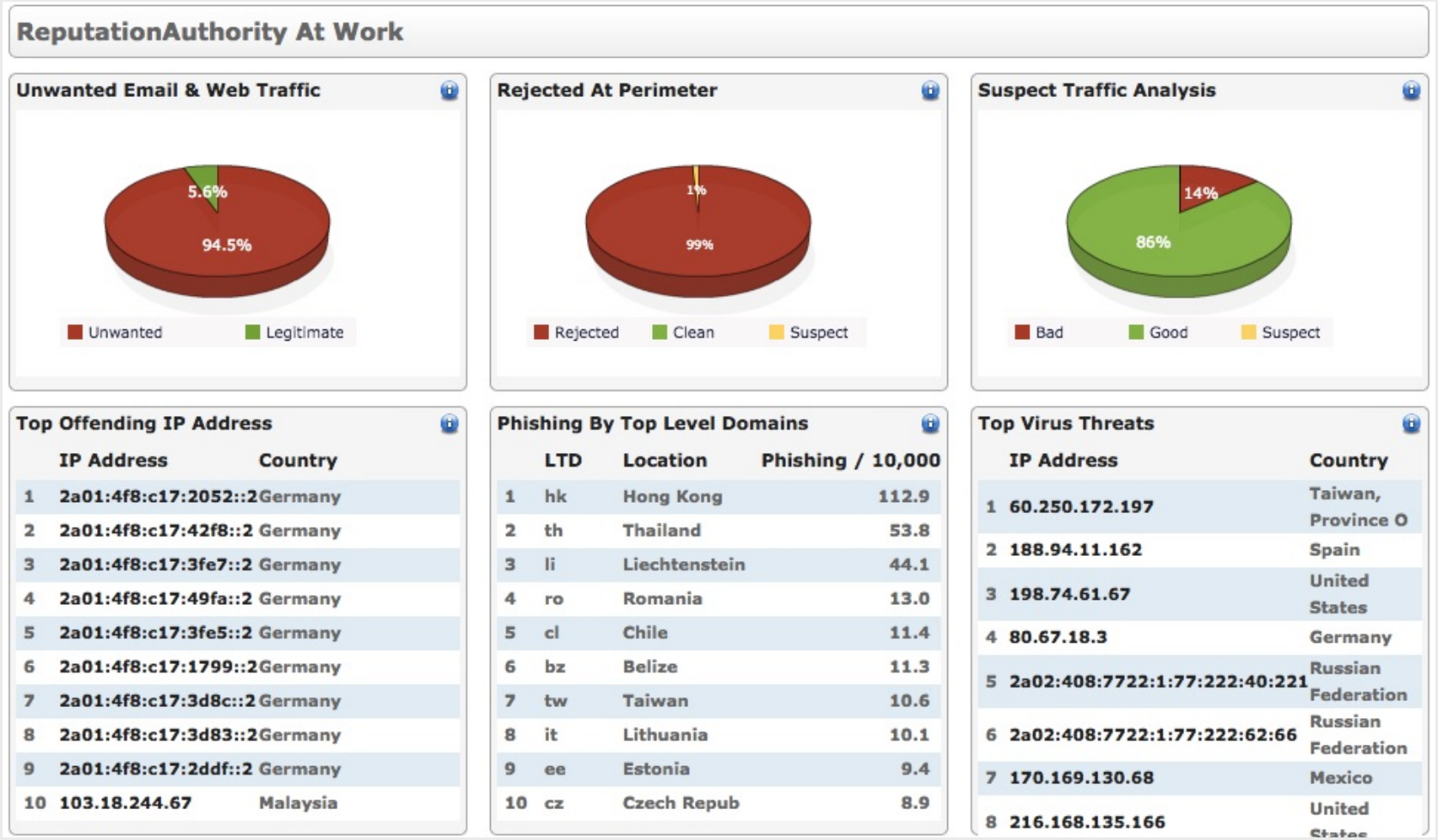
Showing 1 to 10 of 345 entries First Previous 1 2 3 4 5 Next Last

Source: **WORLD IPv6 LAUNCH - (22/3/2023)**



Source: **GOOGLE - (22/3/2023)**

… and So Are IPv6 Security Threats!



ReputationAuthority At Work

Unwanted Email & Web Traffic

Rejected At Perimeter

Suspect Traffic Analysis

Top Offending IP Address

	IP Address	Country
1	2a01:4f8:c17:2052::2	Germany
2	2a01:4f8:c17:42f8::2	Germany
3	2a01:4f8:c17:3fe7::2	Germany
4	2a01:4f8:c17:49fa::2	Germany
5	2a01:4f8:c17:3fe5::2	Germany
6	2a01:4f8:c17:1799::2	Germany
7	2a01:4f8:c17:3d8c::2	Germany
8	2a01:4f8:c17:3d83::2	Germany
9	2a01:4f8:c17:2ddf::2	Germany
10	103.18.244.67	Malaysia

Phishing By Top Level Domains

	LTD	Location	Phishing / 10,000
1	hk	Hong Kong	112.9
2	th	Thailand	53.8
3	li	Liechtenstein	44.1
4	ro	Romania	13.0
5	cl	Chile	11.4
6	bz	Belize	11.3
7	tw	Taiwan	10.6
8	it	Lithuania	10.1
9	ee	Estonia	9.4
10	cz	Czech Repub	8.9

Top Virus Threats

	IP Address	Country
1	60.250.172.197	Taiwan, Province O
2	188.94.11.162	Spain
3	198.74.61.67	United States
4	80.67.18.3	Germany
5	2a02:408:7722:1:77:222:40:221	Russian Federation
6	2a02:408:7722:1:77:222:62:66	Russian Federation
7	170.169.130.68	Mexico
8	216.168.135.166	United States

IPv6 Security Statements

1	2	3	4	**5**	6	7	8

- IPv6 is just IPv4 with 128 bits addresses
- There is nothing new

Reason:

- Routing and switching work the same way

Reality:

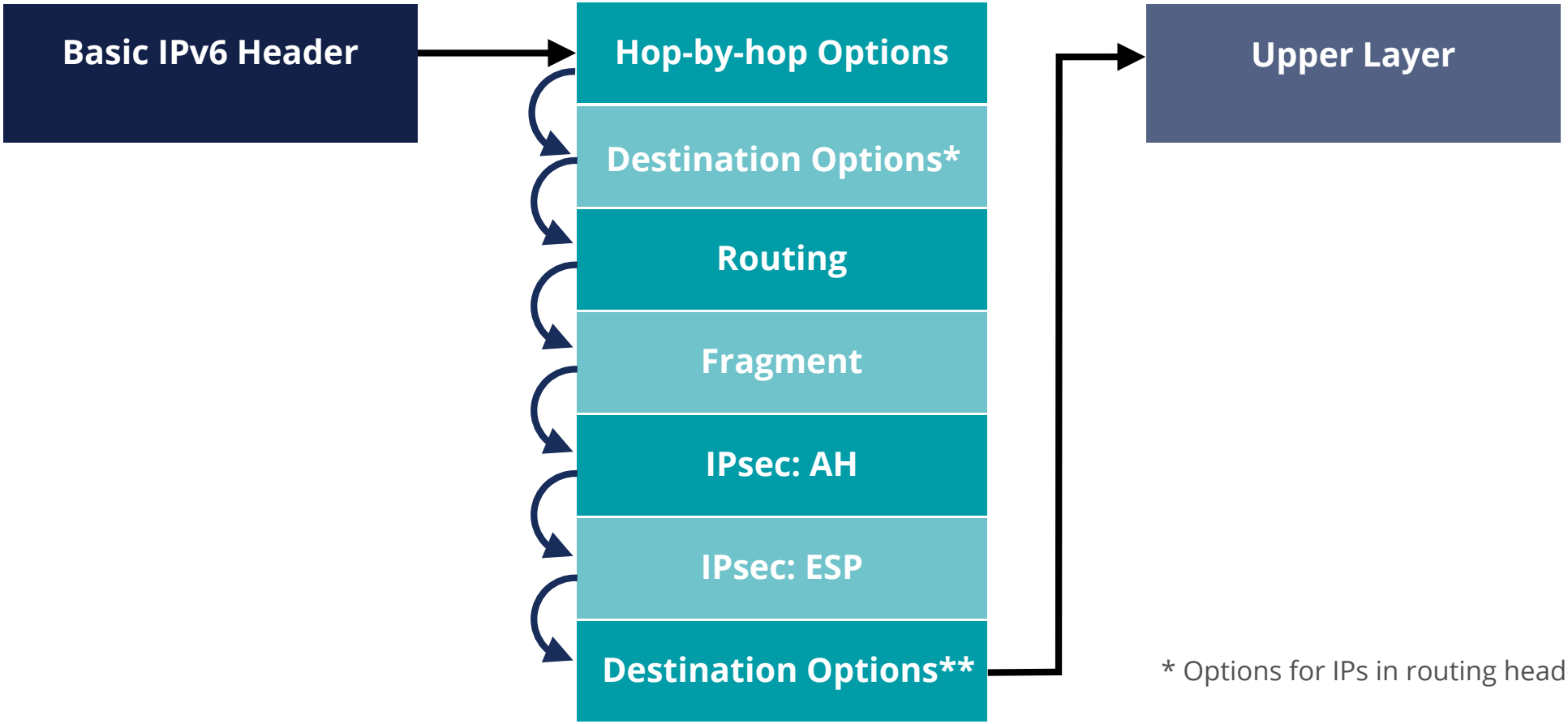
- Whole new addressing architecture
- Many associated new protocols

IPv6 vs IPv4

- IPv6 quite similar to IPv4, many reusable practices
- IPv6 security compared with IPv4:

No changes with IPv6 | **Changes with IPv6** | **New IPv6 issues**

IPv6 Extension Headers



* Options for IPs in routing header

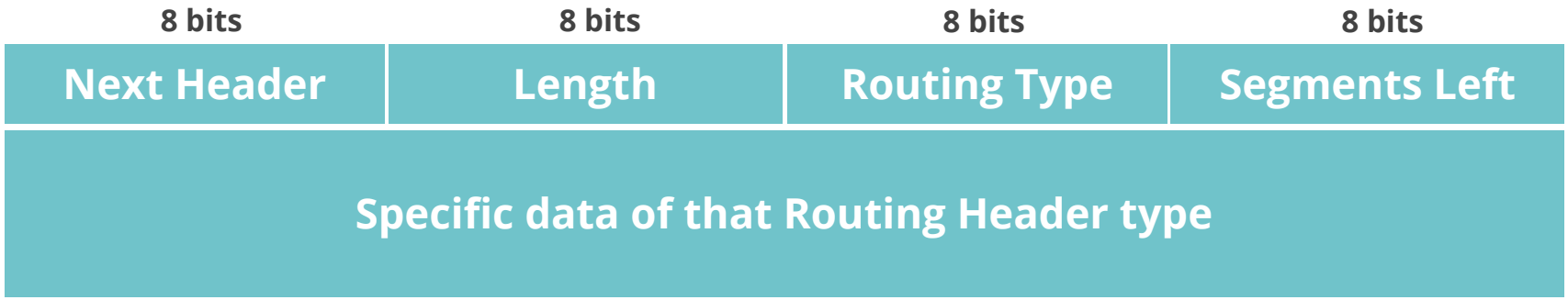
** Options for destination IP

- Flexibility means **complexity**
- Security devices / software must process the **full chain of headers**
- Firewalls must be able to filter based on **Extension Headers**

Routing Header

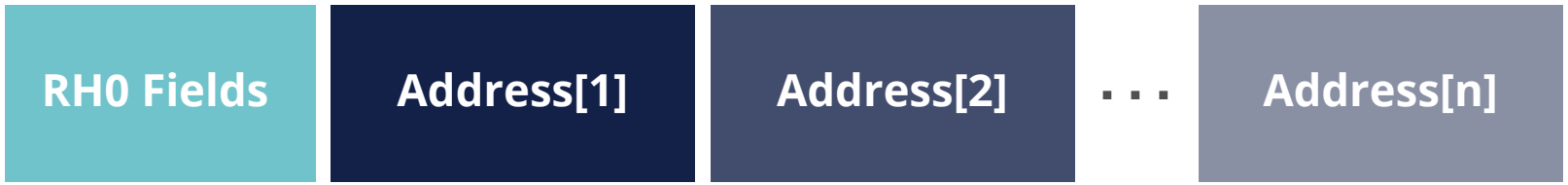
Includes one or more IPs that should be "*visited*" in the path

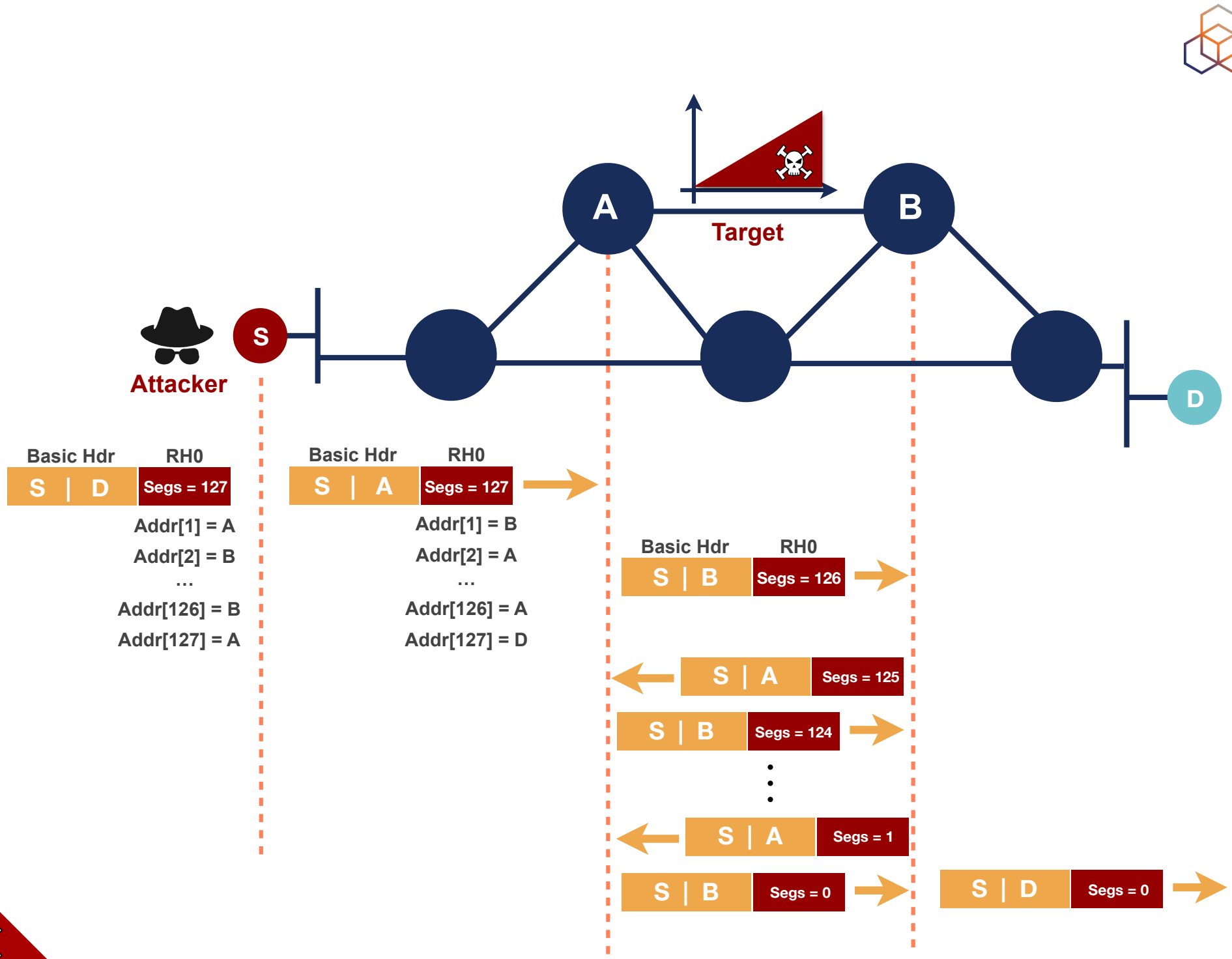
- Processed by the **visited routers**



Routing Header Threat

- **Routing Header** (**Type 0**):
  - RH0 can be used for traffic amplification over a remote path
- **RH0 Deprecated** [*RFC5095*]
  - RH1 deprecated. RH2 (MIPv6), RH3 (RPL) and RH4 (SRH) are valid



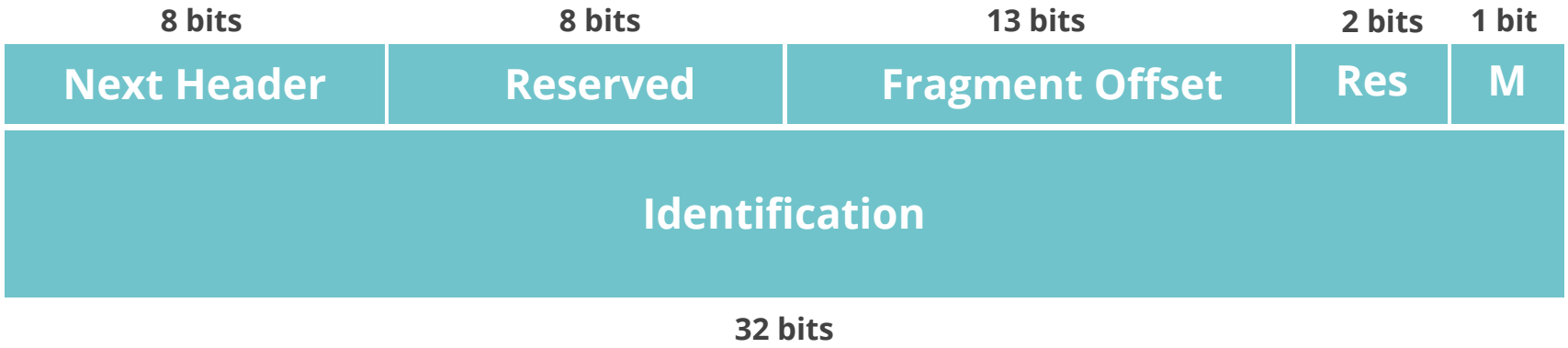

A
B
Target
S
Attacker
D
Basic Hdr
RH0
S | D
Segs = 127
Addr[1] = A
Addr[2] = B
…
Addr[126] = B
Addr[127] = A
Basic Hdr
RH0
S | A
Segs = 127
Addr[1] = B
Addr[2] = A
…
Addr[126] = A
Addr[127] = D
Basic Hdr
RH0
S | B
Segs = 126
S | A
Segs = 125
S | B
Segs = 124
S | A
Segs = 1
S | B
Segs = 0
S | D
Segs = 0

Extension Headers Solutions

- Require security tools to inspect Header Chain properly

Fragment Header

- Used by IPv6 source node to send a packet **bigger than path MTU**
- **Destination host** processes fragment headers

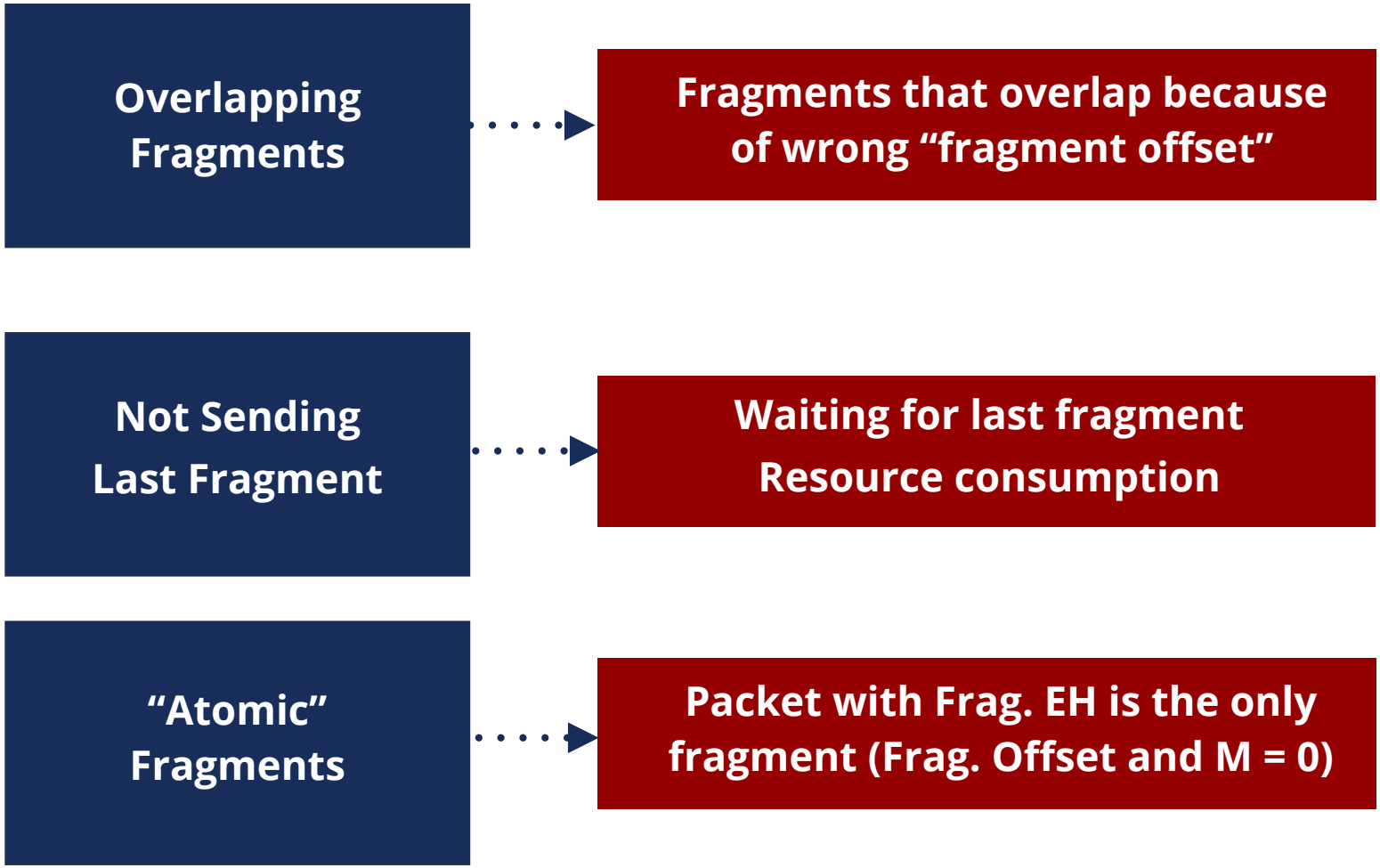


M Flag:

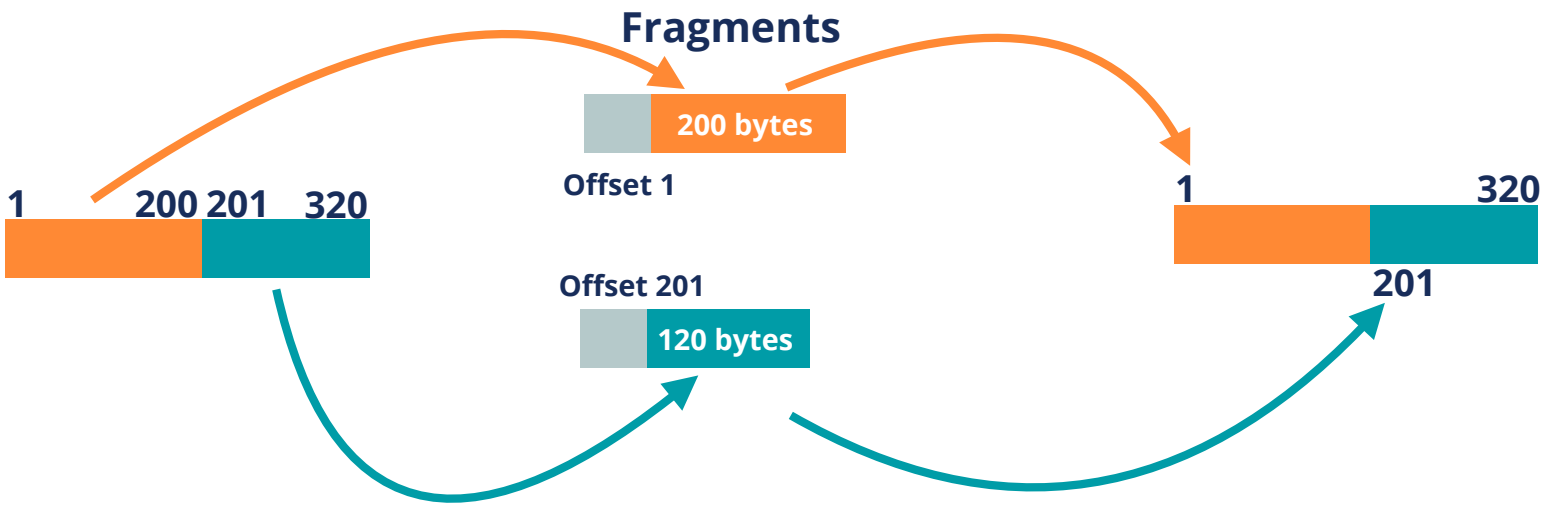
1 = more fragments to come;

0 = last fragment

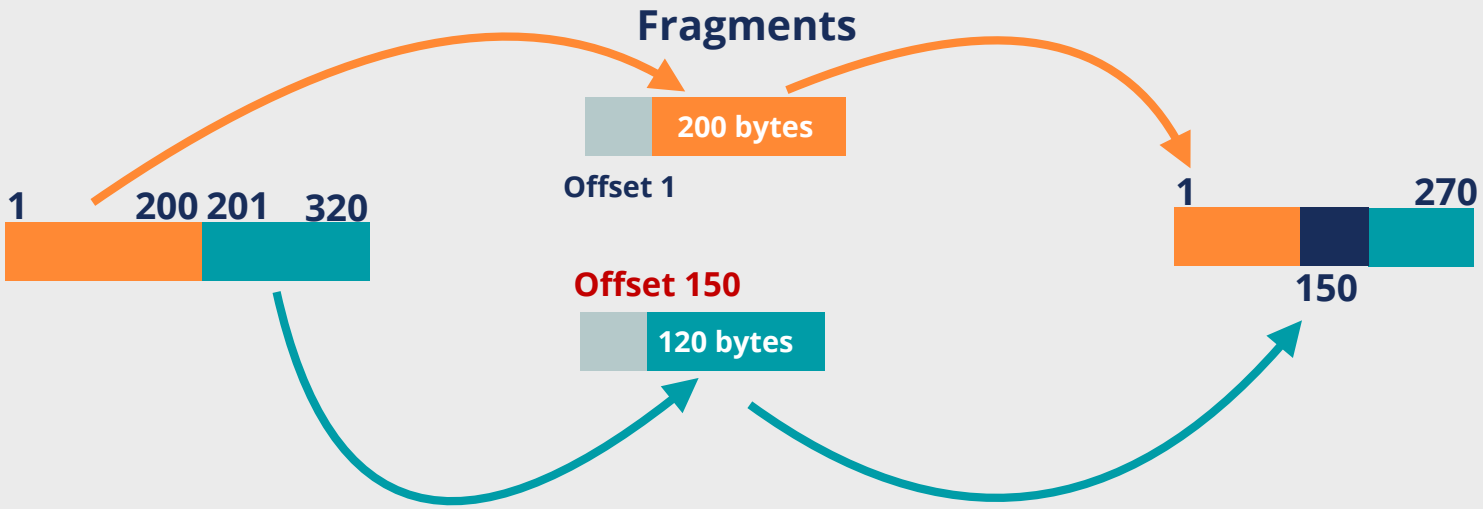
EH Threats: Fragmentation



Overlapping Fragments

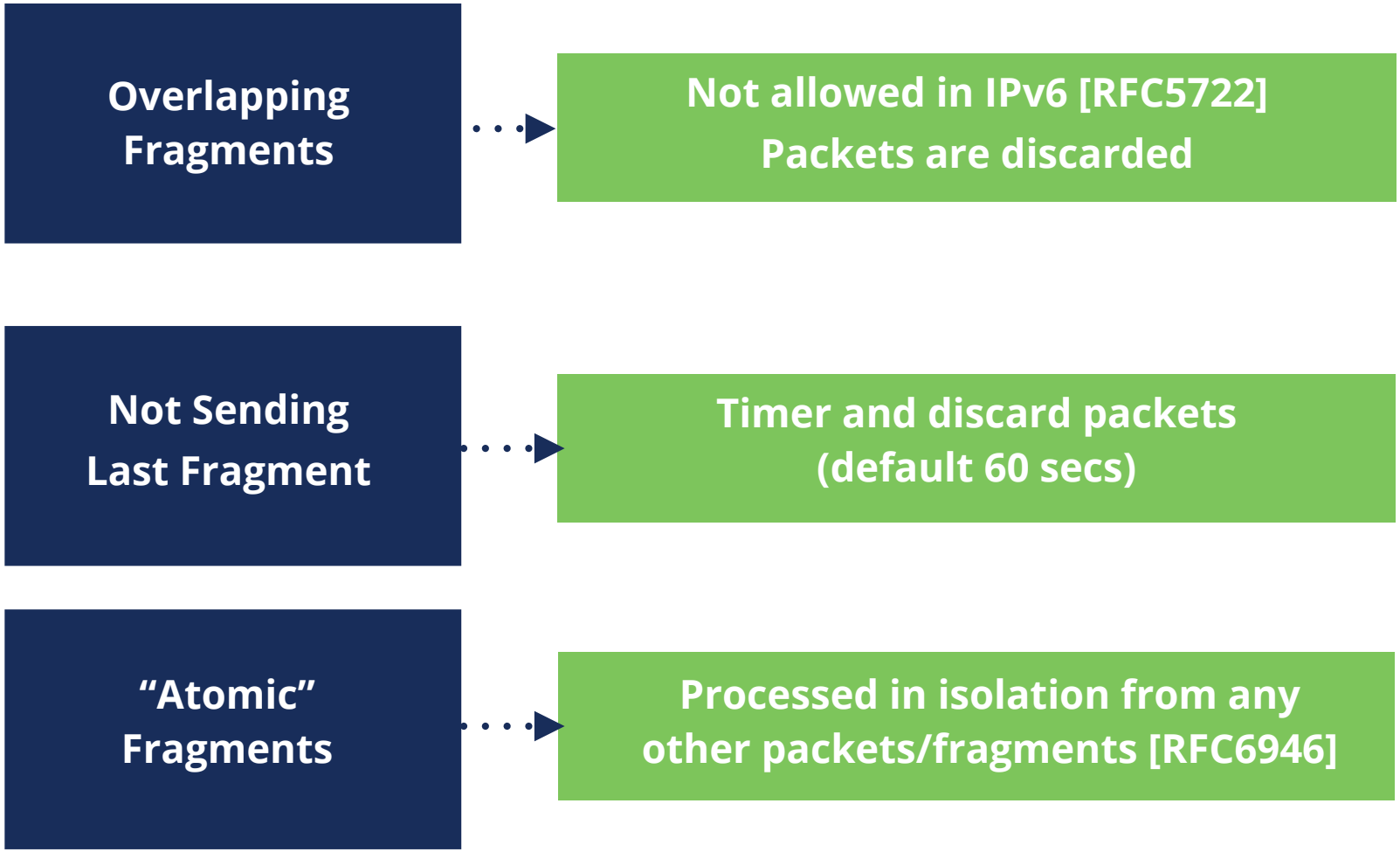


Normal fragments offset say where the data goes



Overlapping fragments have wrong offset values

EH Solutions: Fragmentation



Bypassing RA Filtering/RA-Guard

Using **any** Extension Header

If it only looks at Next Header = 60, it does not detect the RA

Bypassing RA Filtering/RA-Guard

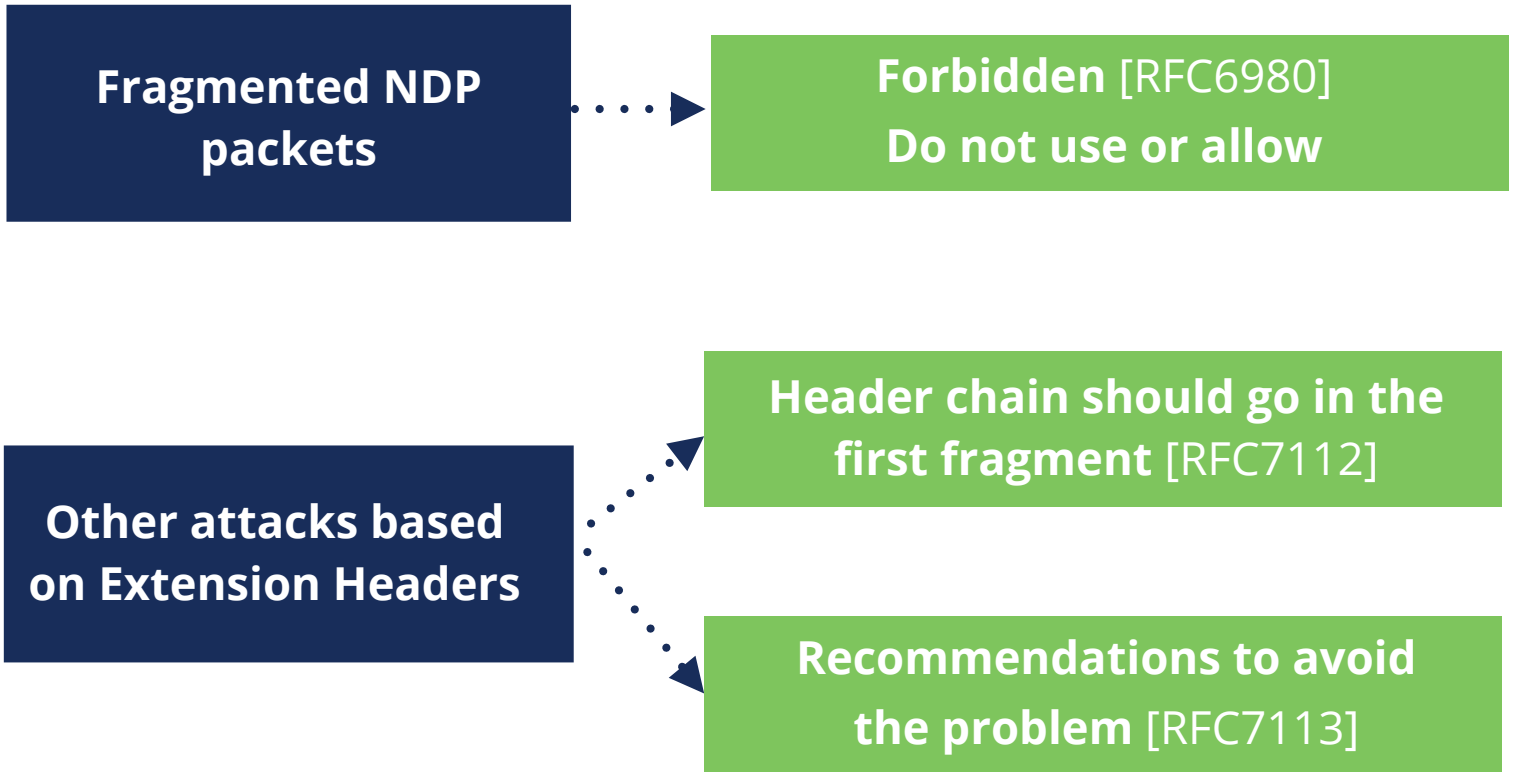
Using **Fragment** Extension Header

Basic IPv6 Header	Fragment	Destination Options
Next Header = 44	*Next Header = 60*	*Next Header = 58*

Basic IPv6 Header	Fragment	Destination Options	ICMPv6: RA
Next Header = 44	*Next Header = 60*	*Next Header = 58*	

Needs all fragments to detect the RA

Extension Headers Solutions



- **Require** security tools to inspect Header Chain properly

NDP Features

Hop Limit = 255

if not then **discard**

NDP has vulnerabilities

[RFC3756]

[RFC6583]

Specification says to use IPsec

impractical, it's not used

SEND [RFC3971]

(SEcure Neighbour Discovery)

Not widely available

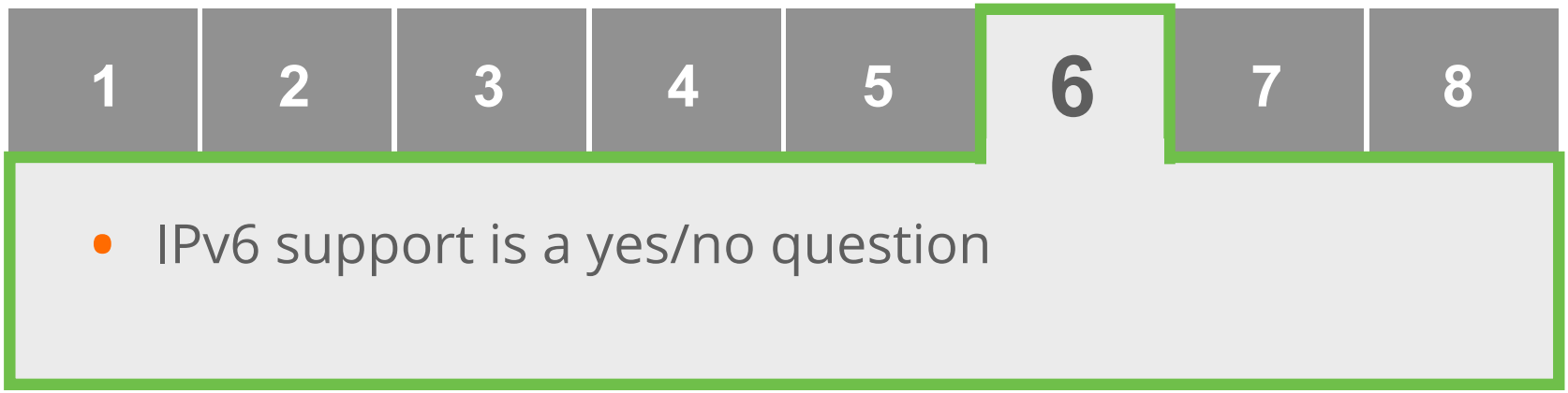
NDP Threats

- **Neighbor Solicitation/Advertisement Spoofing**

- Can be done sending:
  1. **NS** with "source link-layer" option changed
  2. **NA** with "target link-layer" option changed
     - Can send unsolicited **NA** or as an answer to **NS**

- Redirection/DoS attack
- Could be used for a "**Man-In-The-Middle**" attack ?

IPv6 Security Statements



Reason:

- Question: “Does it support IPv6?”
- Answer: “Yes, it supports IPv6”

Reality:

- IPv6 support **is not** a yes/no question
- Features missing, immature implementations, interoperability issues

Devices Categories (RIPE-772)

Host

- **IPSec** (if needed)
- **RH0** [RFC5095]
- **Overlapping Frags** [RFC5722]
- **Atomic Fragments** [RFC6946]
- **NDP Fragmentation** [RFC6980]
- **Header chain** [RFC7112]
- **Stable IIDs** [RFC8064][RFC7217] [RFC7136]
- **Temp. Address Extensions** [RFC8981]
- **Disable if not used:** LLMNR, mDNS, DNS-SD, transition mechanisms

Switch

- **HOST +**
- **IPv6 ACLs**

FHS

- **RA-Guard** [*RFC6105*]
- **DHCPv6 guard**
- **IPv6 snooping**
- **IPv6 source / prefix guard**
- **IPv6 destination guard**
- **MLD snooping** [RFC4541]
- **DHCPv6-Shield** [RFC7610]

Router

- **HOST +**
- **Ingress Filtering and RPF**
- **DHCPv6 Relay** [RFC8213]

OSPFv3

- **Auth.** [RFC4552]
- **or / and** [RFC7166]

IS-IS

- [RFC5310]
- **or, less preferred,** [RFC5304]

MBGP

- **TCP-AO** [RFC5925]
- **MD5 Signature Option** [RFC2385] *Obsoleted*
- **MBGP Bogon prefix filtering**

Security Equipment

- **HOST +**
- **Header chain** [RFC7112]
- **Support EHs Inspection**
- **ICMPv6 fine grained filtering**
- **Encapsulated Traffic Inspection**
- **IPv6 Traffic Filtering**

CPE

- **Router**
- **Security Equipment**
- **DHCPv6 Server Privacy Issues**

Security Tools

Type	Can be used for	Examples
Packet Generators	Assessing IPv6 security	Scapy, nmap, Ostinato, TRex
	Testing implementations	
	Learning about protocols	
	Proof of concept of attacks/protocols	
Packet Sniffers/ Analyzers	Understanding attacks and security measures	tcpdump, Scapy, Wireshark, termshark
	Learning about protocols and implementations	
	Troubleshooting	
Specialised Toolkits	Assessing IPv6 security	THC-IPV6, The IPv6 Toolkit, Ettercap
	Learning about protocols and implementations	
	Proof of concept of attacks/protocols	
	Learn about new attacks	
Scanners	Finding devices and information	nmap, OpenVAS
	Proactively protect against vulnerabilities	
IDS/IPS	Understanding attacks and security measures	Snort, Suricata, Zeek
	Learning about protocols and implementations	
	Assessing IPv6 security	
	Learn about new attacks	

IPv6 Security Statements

1	2	3	4	5	6	7	8

- IPv6 is not a security problem in my IPv4-only network

Reason:

- Networks only designed and configured for IPv4

Reality:

- IPv6 available in many hosts, servers, and devices
- Unwanted IPv6 traffic. Protect your network

- In IPv4-only infrastructure expect **dual-stack hosts**:
  - VPNs or tunnels
  - Undesired local IPv6 traffic
  - Automatic Transition Mechanisms
  - Problems with rogue RAs

Dual-stack

	
Bigger attack surface	Protect IPv6 at the same level as IPv4
GUA Addresses	Filter end-to-end IPv6 properly
Use one IP version to attack the other	Don’t trust “IPv4-only”

IPv6 Security Statements

1	2	3	4	5	6	7	8

- It is not possible to secure an IPv6 network
- Lack of resources and features

Reason:

- Considering IPv6 completely different than IPv4
- Think there are no BCPs, resources or features

Reality:

- Use IP independent security policies
- There are BCPs, resources and features

IPv6 vs IPv4

- IPv6 quite similar to IPv4, many reusable practices
- IPv6 security compared with IPv4:

No changes with IPv6 | **Changes with IPv6** | **New IPv6 issues**

Security Tools

Type	Can be used for	Examples
Packet Generators	Assessing IPv6 security	Scapy, nmap, Ostinato, TRex
	Testing implementations	
	Learning about protocols	
	Proof of concept of attacks/protocols	
Packet Sniffers/ Analyzers	Understanding attacks and security measures	tcpdump, Scapy, Wireshark, termshark
	Learning about protocols and implementations	
	Troubleshooting	
Specialised Toolkits	Assessing IPv6 security	THC-IPV6, The IPv6 Toolkit, Ettercap
	Learning about protocols and implementations	
	Proof of concept of attacks/protocols	
	Learn about new attacks	
Scanners	Finding devices and information	nmap, OpenVAS
	Proactively protect against vulnerabilities	
IDS/IPS	Understanding attacks and security measures	Snort, Suricata, Zeek
	Learning about protocols and implementations	
	Assessing IPv6 security	
	Learn about new attacks	

Rogue RA Solutions

1. **Link Monitoring**
2. **SEND**
3. **MANUAL CONFIGURATION**
   + Disable Autoconfig
4. **Host Packet Filtering**
5. **Router Preference Option**
   [*RFC4191*]
6. **ACLs on Switches**
7. **RA Snooping on Switches** (RA GUARD)

First Hop Security

- Security implemented **on switches**
- There is a number of techniques available:
  - RA-GUARD
  - IPv6 Snooping (*ND inspection* + *DHCPv6 Snooping*)
  - IPv6 Source / Prefix Guard
  - IPv6 Destination Guard (*or ND Resolution rate limiter*)
  - MLD Snooping
  - DHCPv6 Guard

Routing Protocols Authentication

	Authentication Options	Comments
RIPng	- No authentication - IPsec (general recommendation)	- RIPv2-like MD5 no longer available - IPSec not available in practice
OSPFv3	- IPsec [RFC4552] - Authentication Trailer [RFC7166]	- ESP or AH. Manual keys - Hash of OSPFv3 values. Shared key
IS-IS	- HMAC-MD5 [RFC5304] - HMAC-SHA [RFC5310]	- MD5 not recommended - Many SHA, or any other hash
MBGP	- TCP MD5 Signature Option [RFC2385] - TCP-AO [RFC5925]	- Protects TCP. Available. Obsoleted - Protects TCP. Recommended

Securing Routing Updates

- IPsec is a general solution for IPv6 communication
  - In practice not easy to use

- OSPFv3 specifically states [RFC4552]:
  1. ESP **must** be used
  2. Manual Keying

- Other protocols: **No options available**

Conclusions

- Security options available for IPv6 routing protocols

- Try to use them:
  - Depending on the protocol you use
  - At least at the same level as IPv4

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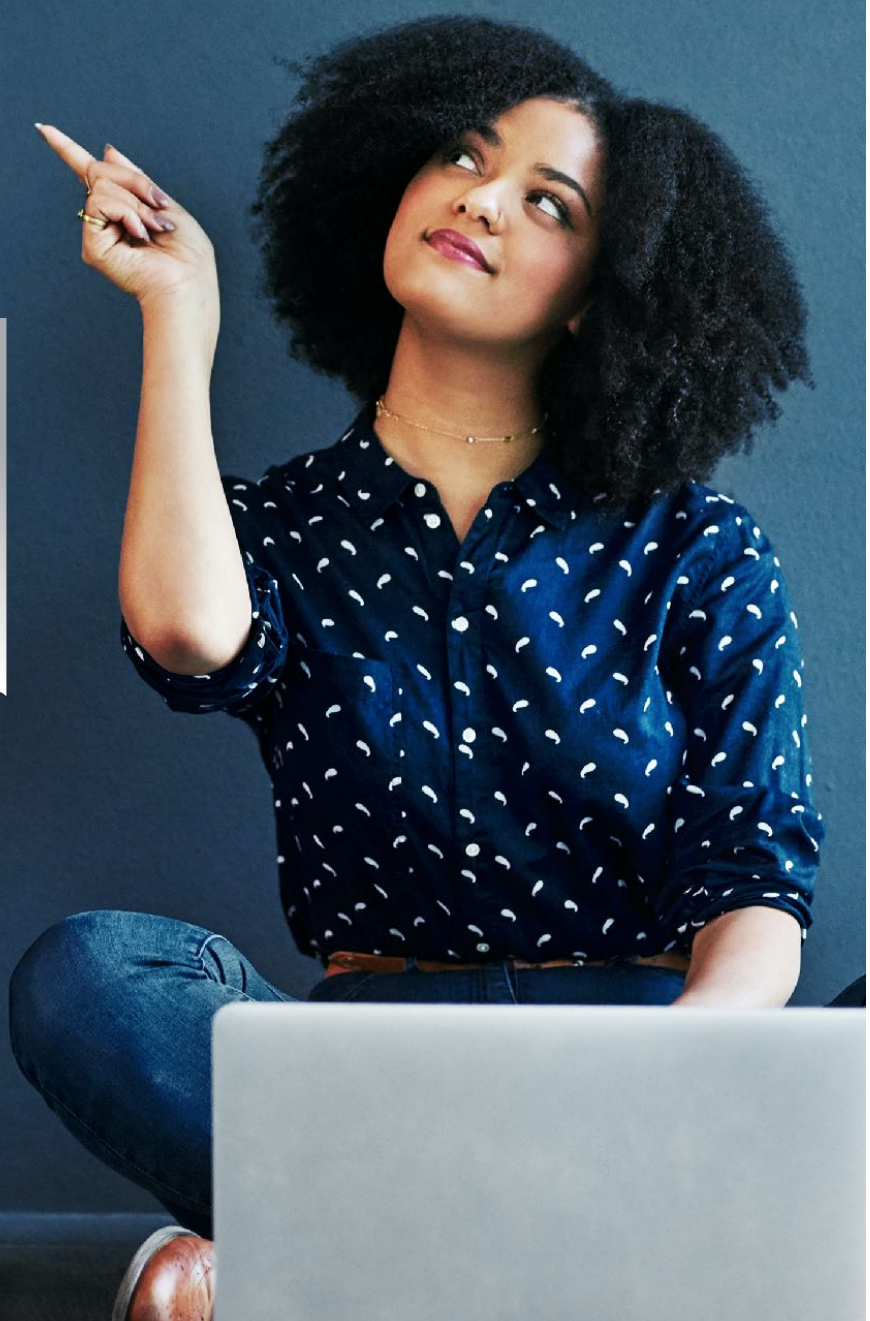


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