IPv6 Extension Headers: Devil or Angel in Disguise?

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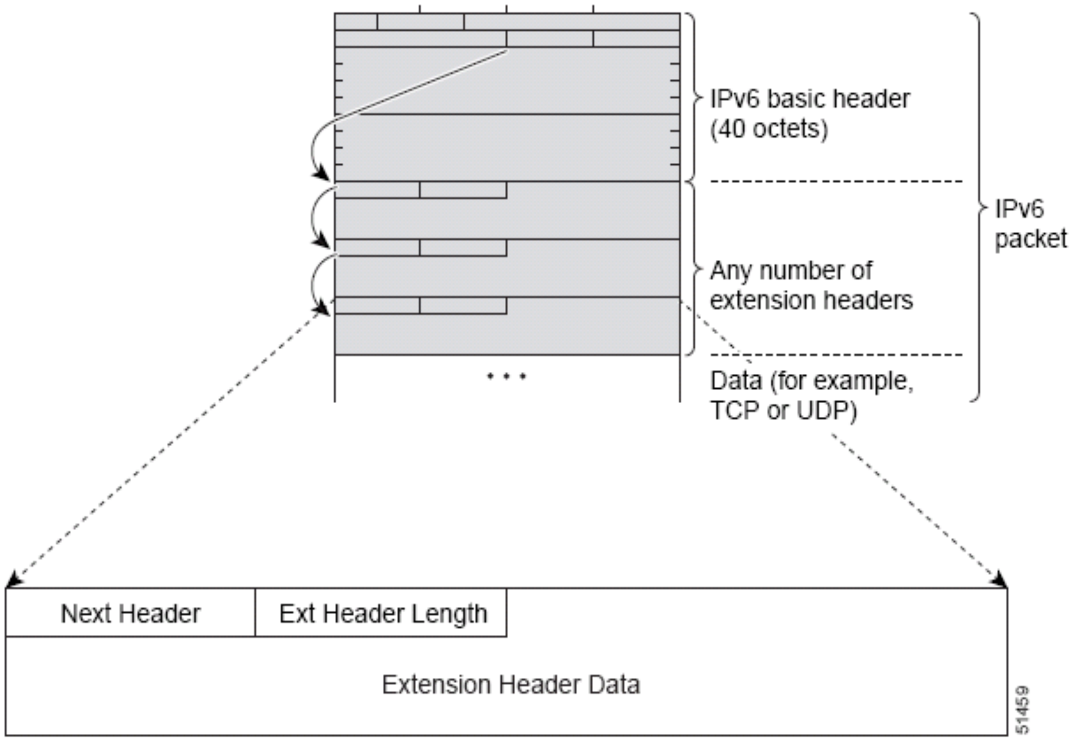
Extension Header Lab with Scapy

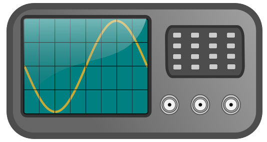
IPv6 Extension Header

Some protocols that require Ext Headers:

- IPv6 Fragmentation
- IPsec (AH and ESP)
- Mobile IPv6
- RPL (RFC 6554)
- Segment Routing
- iOAM6

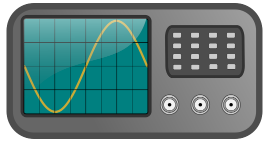


Packet Forgery with SCAPY



- Scapy is a open source packet forgery tool built on Python
- Powerful albeit complex to understand and to use:

```
evyncke@host1:~# scapy
Welcome to Scapy (2.1.0)
>>> target="2001:db8:23:0:60de:29ff:fe15:2”
>>> packet=IPv6(dst=target)/ICMPv6EchoRequest(id=0x1234, seq=RandShort(),
  data="ERIC")
>>> sr1(packet)
Begin emission:
Finished to send 1 packets.
Received 2 packets, got 1 answers, remaining 0 packets
<IPv6  version=6L tc=0L fl=0L plen=12 nh=ICMPv6 hlim=62
  src=2001:db8:23:0:60de:29ff:fe15:2 dst=2001:db8:1:0:60de:29ff:fe15:1 |
  <ICMPv6EchoReply  type=Echo Reply code=0 cksum=0xdb04 id=0x1234 seq=0x956a
  data='ERIC' |>>
```



Let’s Try it With Routing Header 0 & Tcpdump

```
a="2001:DB8:1::1"
b="2001:DB8:23::2”
route=[]
for i in range(0, 30):
  route.append(a)
  route.append(b)
packet=IPv6(dst=b,hlim=255)/IPv6ExtHdrRouting(addresses=route,type=0)/ICMPv6EchoRequest()
sr1(packet)
```

Using a recent IOS, the router refuses to process Routing Header Type 0

```
IP6 (hlim 63, next-header ICMPv6 (58) payload length: 384) 2001:db8:23::2 > scapy_host: [icmp6
  sum ok] ICMP6, parameter problem, length 384, errorneous - octet 42
```

Fragmentation Used in IPv4 by Attackers ... Also applicable to IPv6 of course

- Great evasion techniques
  - Some firewalls do not process fragments except for the first one
  - Some firewalls cannot detect overlapping fragments with different content
- IPv4 tools like whisker, fragrout, etc.
- Makes firewall and network intrusion detection harder
- Used mostly in DoSing hosts, but can be used for attacks that compromise the host
  - Send a fragment to force states (buffers, timers) in OS

  - See also: http://insecure.org/stf/secnet_ids/secnet_ids.html 1998!

Parsing the Extension Header Chain Fragments and Stateless Filters

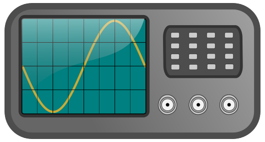
- RFC 3128 is not applicable to IPv6
- Layer 4 information could be in 2^{nd} fragment
- But, stateless firewalls could not find it if a previous extension header is fragmented

IPv6 hdr	HopByHop	Routing	Fragment1	Destination …		
IPv6 hdr	HopByHop	Routing	Fragment2	… Destination	TCP	Data

Layer 4 header is in 2^{nd} fragment, Stateless filters have no clue where to find it!

- But, RFC6980: "nodes MUST silently ignore NDP … if packets include a fragmentation header
- But, RFC7112: "A host that receives a First Fragment that does not satisfy… SHOULD discard the packet

Fragment Obfuscation with Scapy & tcpdump

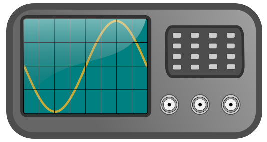


```
>>> packet=IPv6(dst=dst)/IPv6ExtHdrDestOpt(options=PadN(optdata='A'*20))/
  TCP(sport=sport,dport=22,flags="S", seq=100)
>>> frag1=IPv6(dst=dst)/IPv6ExtHdrFragment(nh=60, id=0xabbababe, m=1, offset=0)/str(packet)
  [40:48]
>>> frag2=IPv6(dst=dst)/IPv6ExtHdrFragment(nh=60, id=0xabbababe, m=0, offset=1)/str(packet)
  [48:84]
>>> send(frag1)
>>> send(frag2)
```

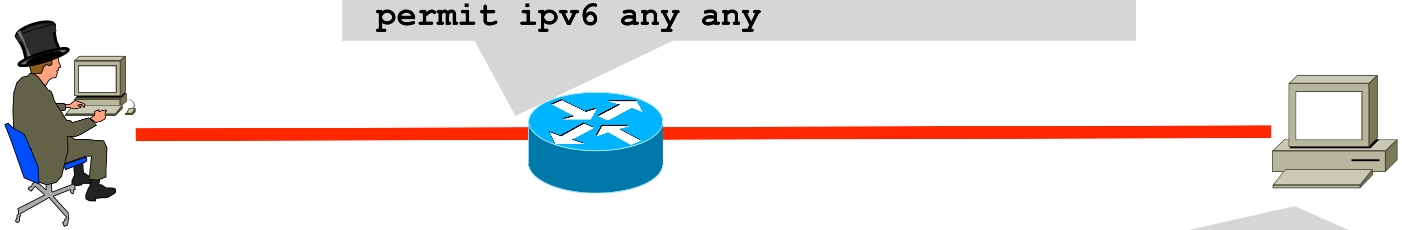
```
IP6 (hlim 64, next-header Fragment (44) payload length: 16) 2001:...:1 > 2001:...:2: frag (0xabbababe:0|8) [|DSTOPT]
   0x0000:  6000 0000 0010 2c40 2001 0db8 0001 0000  `.....,@........
   0x0010:  60de 29ff fe15 0001 2001 0db8 0023 0000  `.)..........#..
   0x0020:  60de 29ff fe15 0002 3c00 0001 abba babe  `.).....<.......
   0x0030:  0602 0114 4141 4141                      ....AAAA

IP6 (hlim 64, next-header Fragment (44) payload length: 44) 2001:...:1 > 2001:...:2: frag (0xabbababe:8|36)
   0x0000:  6000 0000 002c 2c40 2001 0db8 0001 0000  `....,,@........
   0x0010:  60de 29ff fe15 0001 2001 0db8 0023 0000  `.)..........#..
   0x0020:  60de 29ff fe15 0002 3c00 0008 abba babe  `.).....<.......
   0x0030:  4141 4141 4141 4141 4141 4141 4141 4141  AAAAAAAAAAAAAAAA
   0x0040:  47b3 0016 0000 0064 0000 0000 5002 2000  G......d....P...
   0x0050:  da35 0000
```

Let’s Try the Naïve ACL...



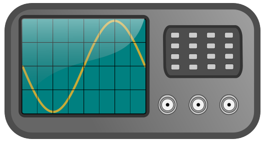
```
ipv6 access-list NO_SSH
 deny tcp any any eq 22 log
 permit ipv6 any any
```



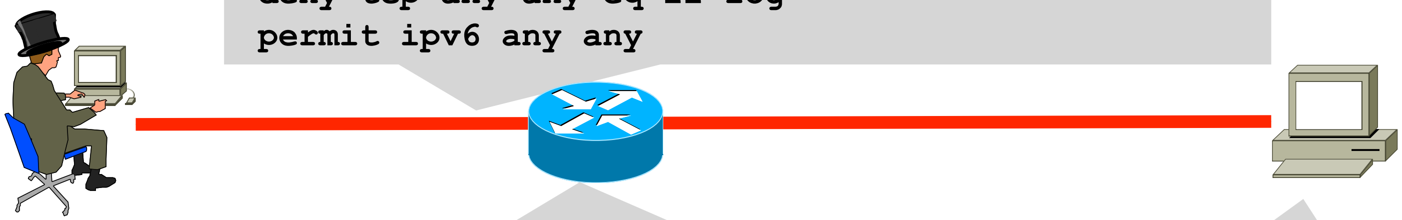
```
IP6 (hlim 62, next-header Fragment (44) payload length: 16) 2001:..:1 > 2001:..:2: frag
(0xabbababe:0|8) [|DSTOPT]
IP6 (hlim 62, next-header Fragment (44) payload length: 44) 2001:..:1 > 2001:..:2: frag
(0xabbababe:8|36)

SSH accepts connection and replies
IP6 (hlim 64, next-header TCP (6) payload length: 24) 2001:...:2.22 > 2001:...:1.18355: Flags
[S.], cksum 0x138c (correct), seq 621319016, ack 101, win 5760, options [mss 1440], length 0
```

Let’s Try undetermined_transport...



```
ipv6 access-list NO_SSH2
 deny ipv6 any any undetermined-transport log
 deny tcp any any eq 22 log
 permit ipv6 any any
```



```
%IPV6_ACL-6-ACCESSLOGSP: list NO_SSH2/10 denied tcp
2001:...:1 -> 2001:...:2, 1 packet
```

1st fragment is not received..

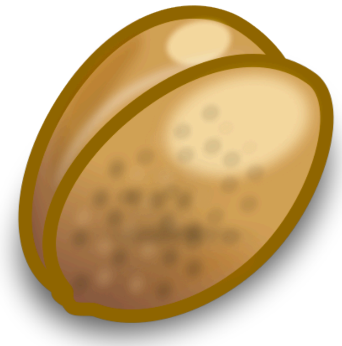
```
IP6 (hlim 62, next-header Fragment (44) payload length: 44) 2001:..:1 > 2001:..:2: frag
(0xabbababe:8|36)
```

Reassembly fails after time-out, connection is never established

Extension Headers for Segment Routing

Segment Routing in a Nutshell

- Segment Routing:
  - **Source based routing model** where the source chooses a path and encodes it in the packet header as an ordered list of segments
  - A segment is effectively an instruction applied to the packet as it traverses its list of segments
  - Segment Routing leverages the source routing architecture defined in RFC2460 for IPv6, including the use of the IPv6 Routing Extension Header



Source: wikimedia

Segment Routing and the Source Based Routing Model

- Segment Routing technology is extensively explained in
  - http://www.segment-routing.net (includes all published IETF drafts)
- Segment Routing data-planes
  - SR-MPLS: segment routing applied to MPLS data-plane
  - **SR-IPv6: segment routing applied to IPv6**
- SR-IPv6 allows Segment Routing do be deployed over non-MPLS networks and/or in areas of the network where MPLS is not present (e.g.: datacenters)
- Segment Routing backward compatibility
  - SR nodes fully interoperate with non-SR nodes
  - No need to have a full network upgrade

Segment Routing Header

- Segment Routing introduces a new Routing Header Type:
  - The Segment Routing Header (SRH)
  - Contains the list of segments the packet should traverse
  - VERY close to what already specified in RFC2460
  - Changes are introduced for:
    > Better flexibility
    > Addressing security concerns raised by RFC5095
- Three SR-IPv6 drafts:
  - draft-ietf-6man-segment-routing-header
  - ~~draft-vyncke-6man-segment-routing-security~~
  - draft-ietf-spring-ipv6-use-cases

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IPv6 Segment Routing Header (SRH)
draft-ietf-6man-segment-routing-header-01

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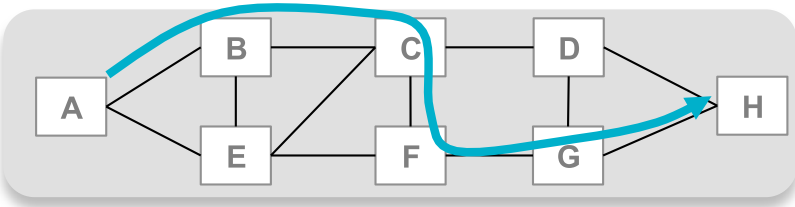
Source Packet Routing in Networking

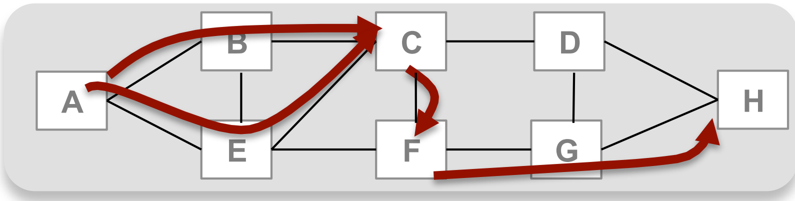
IPv6 SPRING Use Cases
draft-ietf-spring-ipv6-use-cases-06

Segment Routing Model

- Assuming following topology:
  – Node A has two shortest paths to C



- How to best express path: [A, B, C, F, G, H]
- Source routed path with segments: [C,F,H]
  > First segment: set of shortest paths from A to C (ECMP aware)
  > Second segment: adjacency/link from C to F
  > Third segment: shortest path from F to H



SRH: identical to RFC 2460

- Next Header: 8-bit selector. Identifies the type of header immediately following the SRH
- Hdr Ext Len: 8-bit unsigned integer. Defines the length of the SRH header in 8-octet units, not including the first 8 octets
- Routing Type: TBD by IANA (SRH)
- Segment Left: index, in the Segment List, of the current active segment in the SRH. Decremented at each segment endpoint.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Next Header   |  Hdr Ext Len  | Routing Type  | Segments Left |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| First Segment |             Flags             |   RESERVED    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|            Segment List[0] (128 bits IPv6 address)            |
|                                                               |
|                                                               |
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|                                                               |
                              ...
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|            Segment List[n] (128 bits IPv6 address)            |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                                                             //
//         Optional Type Length Value objects (variable)       //
//                                                             //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

SRH: New

- First Segment: offset in the SRH, not including the first 8 octets and expressed in 16-octet units, pointing to the last element of the Segment List
- Flags: HMAC key present, OAM (see later), Clean (remove SRH at egress), ...
- Segment List[n]: 128 bit IPv6 addresses representing each segment of the path. The segment list is encoded in the reverse order of the path: the last segment is in the first position of the list and the first segment is in the last position
- TLV objects (optional): to mark ingress/ ingress SR address, to remember original source address, HMAC key (for security)

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Next Header   |  Hdr Ext Len  | Routing Type  | Segments Left |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| First Segment |           Flags               |  RESERVED     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|            Segment List[0] (128 bits IPv6 address)            |
|                                                               |
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|                                                               |
|                                                               |
                              ...
|                                                               |
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|                                                               |
|            Segment List[n] (128 bits IPv6 address)            |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                                                             //
//         Optional Type Length Value objects (variable)       //
//                                                             //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
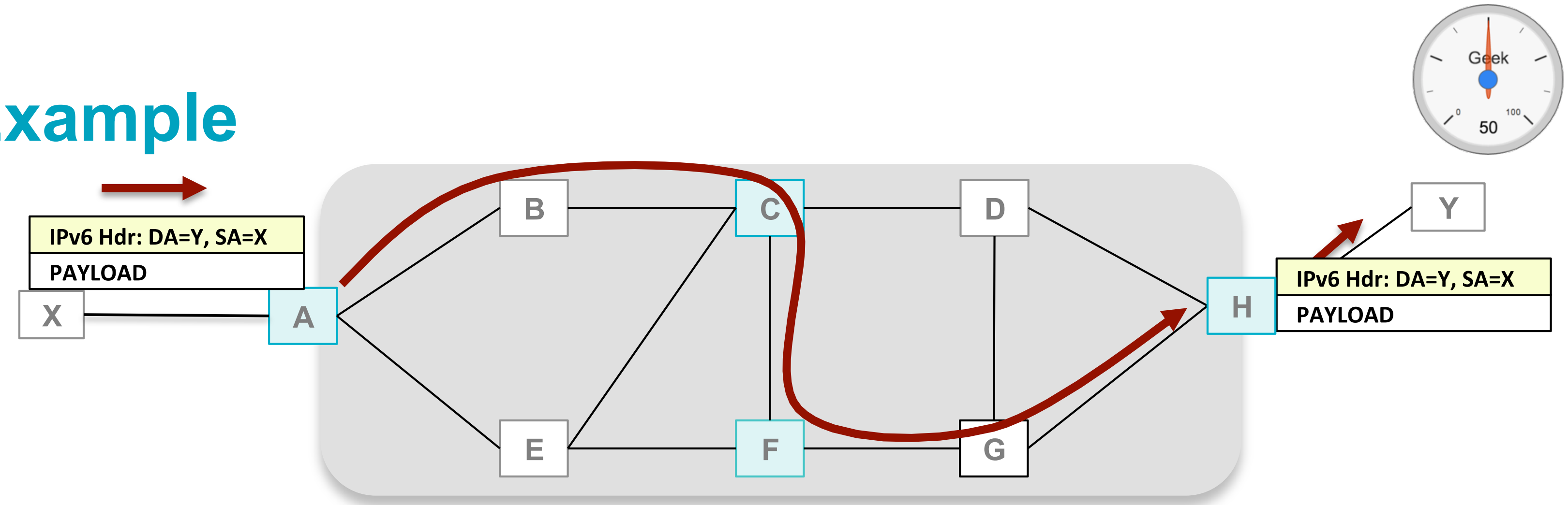
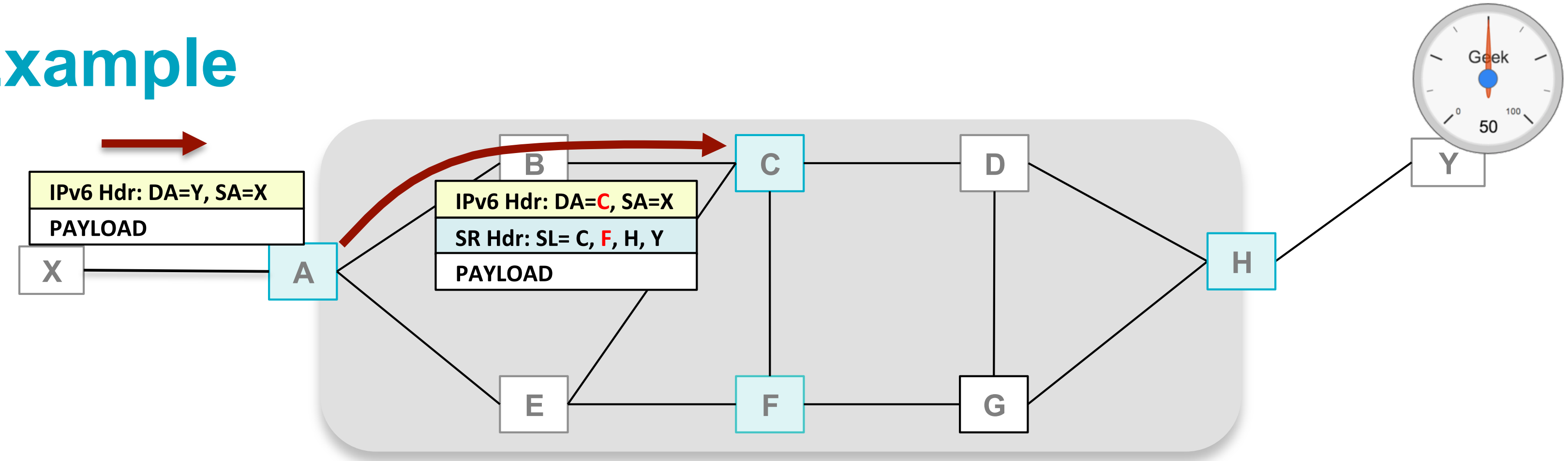

SR-IPv6 Example



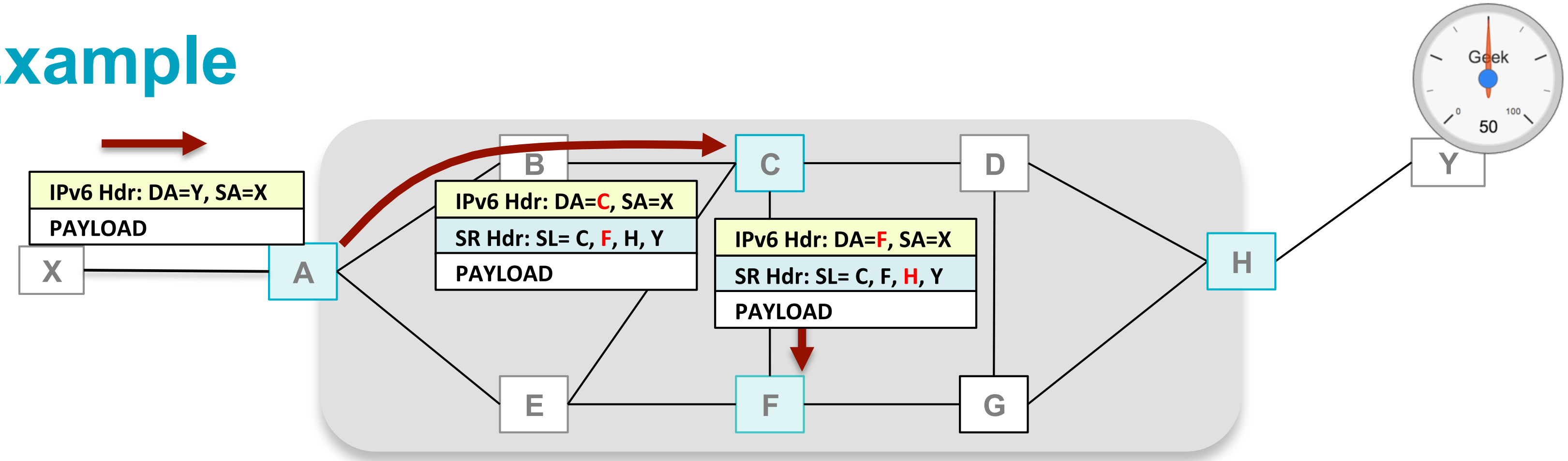
- Example:
  - Classify packets coming from X and destined to Y and forward them across A,B,C,F,G,H path
  - Nodes A, C, F and H are SR capable

SR-IPv6 Example



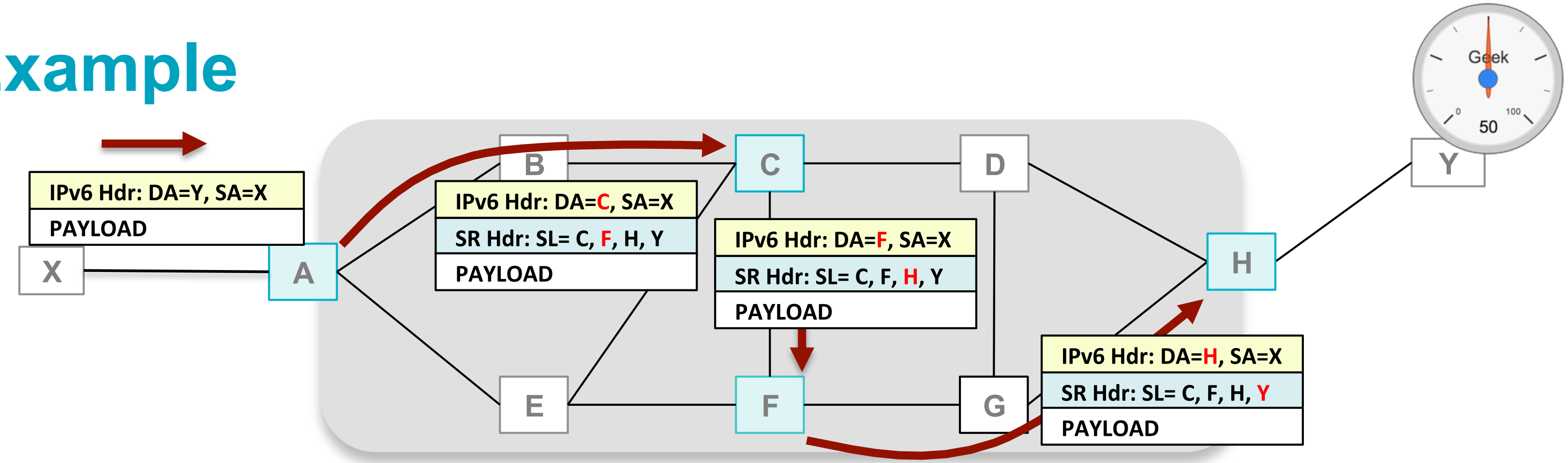
- At ingress, the Segment Routing Header (SRH) contains
  - **Segment List**: C,F,H,Y (original destination address is encoded as last segment of the path)
  - **Segments Left**: identities the next segment of the path (F)
  - **DA** is set as the address of the first segment: C
- Packet is sent towards its DA (C, representing the first segment)
  - Packet can travel across non SR nodes who will just ignore the SRH
  - **RFC2460 mandates only the node in the DA must examine the SRH**

SR-IPv6 Example



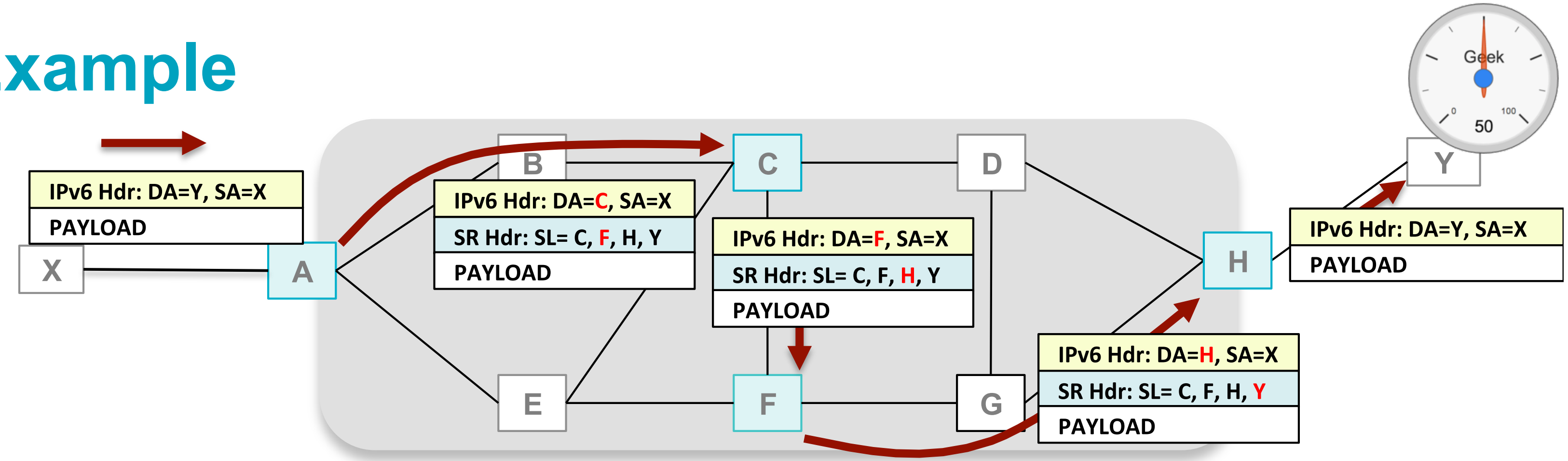
- When packet reaches the segment endpoint C
  - Segment Left is inspected and used in order to update the DA with the next segment address: F
  - Segment Left is decremented: now indicates next segment: H
  - Packet is sent towards its DA

SR-IPv6 Example



- When packet reaches the segment endpoint F the same process is executed:
  - Segment Left is inspected and used in order to update the DA with the next segment address: H
  - Segment Left is decremented: indicated next as Y (the original DA)
  - Packet is sent towards its DA

SR-IPv6 Example

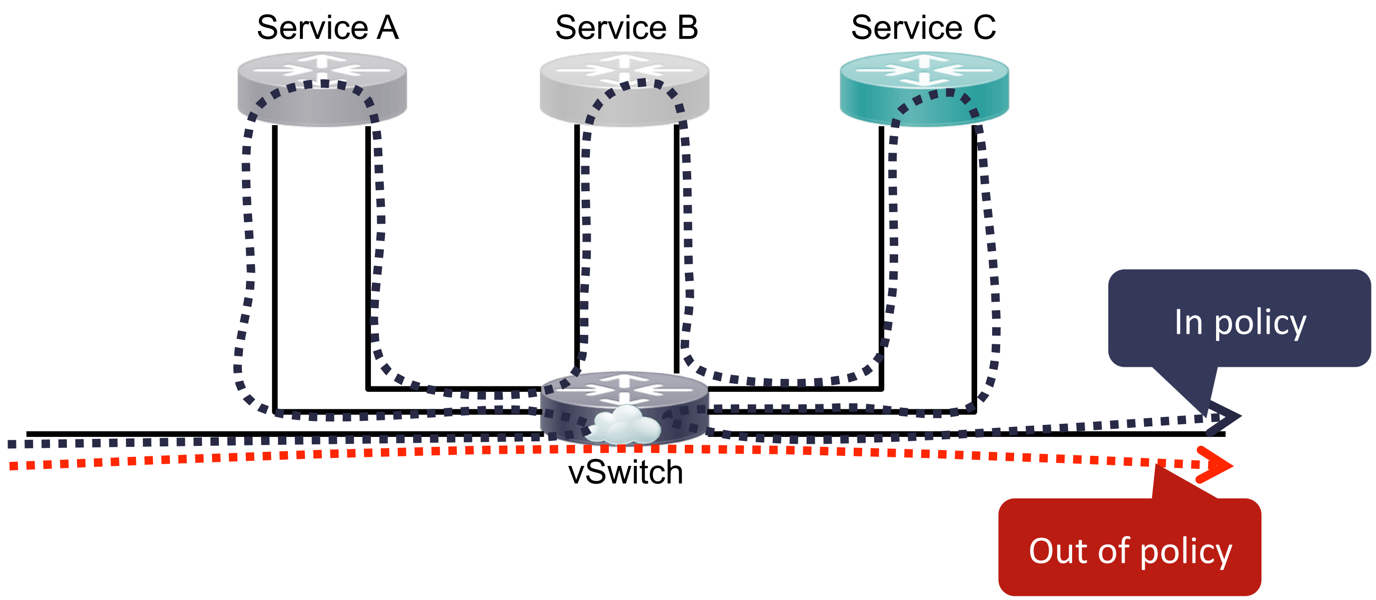


- When packet reaches the segment endpoint H:
  - Segment Left is inspected (== 0) and used in order to update the DA with the next segment address: Y
  - An optional flag (cleanup-flag) in SRH tells H to cleanup the packet and remove the SRH
  - Packet is sent towards its DA

Extension Headers for iOAM

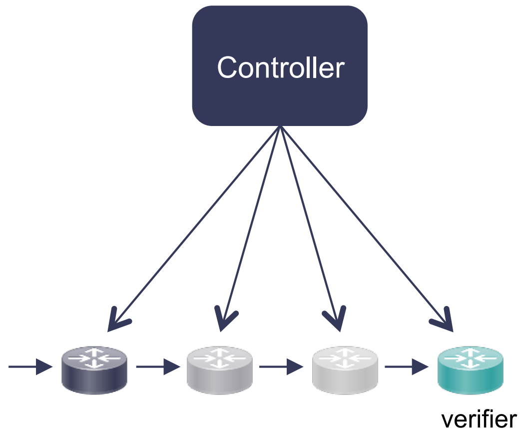
Ensuring Service Chain and Path Integrity

Service Chain: A➧B➧C

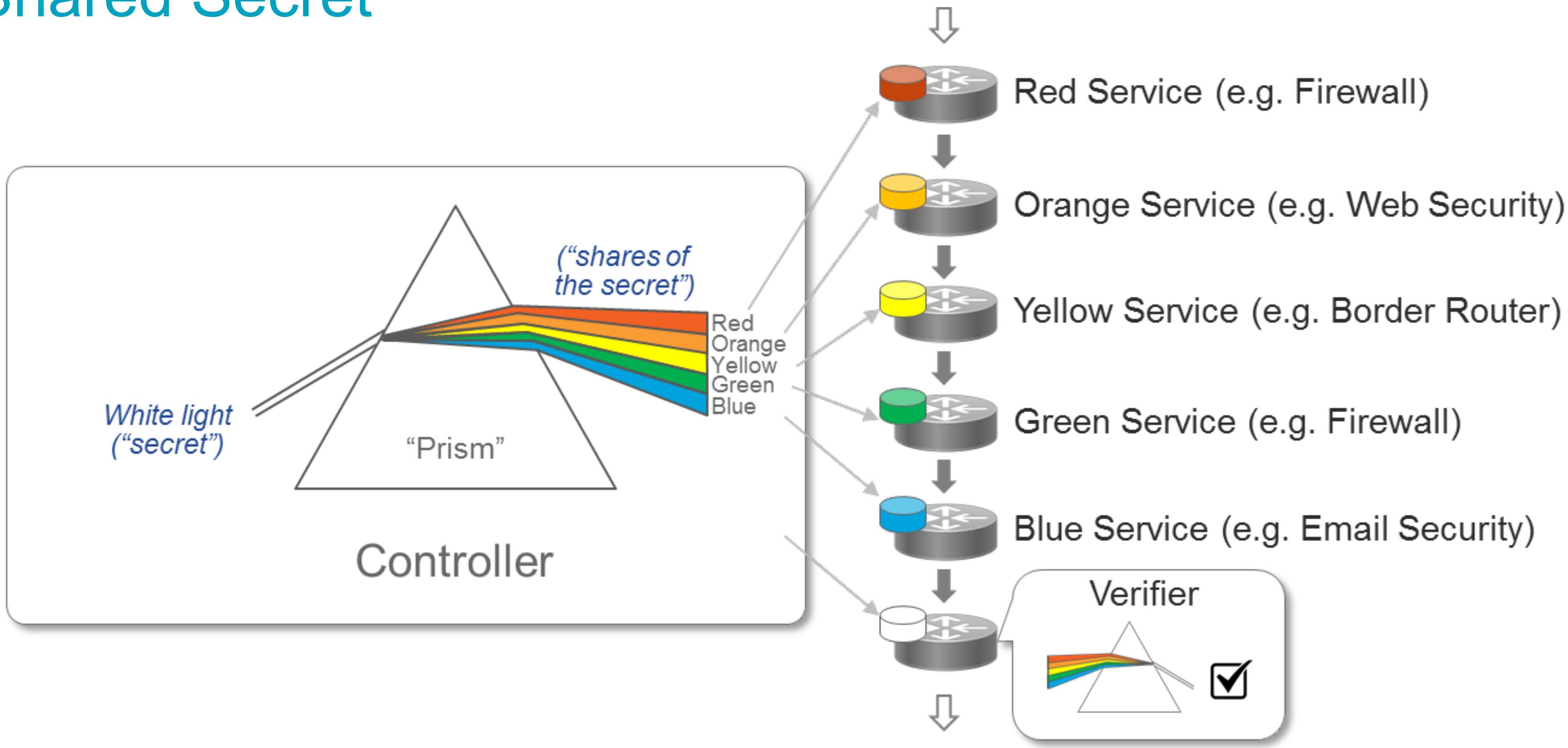


Service Chain Integrity Validation: Approach

- Add meta-data to all packets that traverse a service chain
- The added meta-data allows a verifying node (egress node) to check whether a packet traversed the service chain correctly or not
- Security mechanisms are used on the meta-data to protect against incorrect or misuse (i.e. configuration mistakes, people playing tricks with routing, capturing, spoofing and replaying packets).
- The meta-data is secured through the use of keys. Service functions retrieve the keys from a controller over a secure channel.

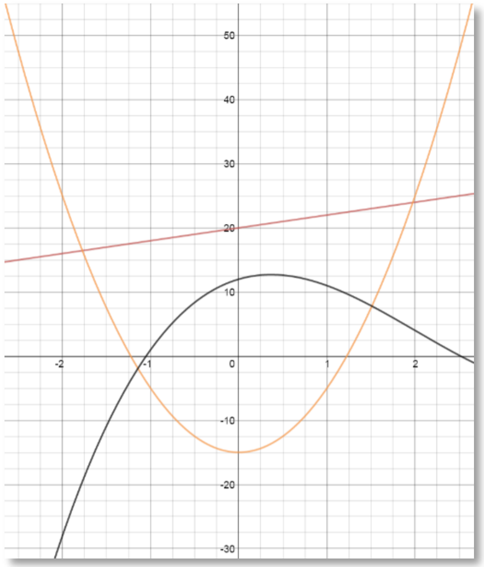


Service Chain Integrity Validation Concept
Shared Secret



Solution Approach: Leveraging Shamir's Secret Sharing

Polynomials 101



$$f2(x) = 10x^2 - 15$$

- Parabola: Min 3 points

$$f1(x) = 2x + 20$$

- Line: Min 2 points

$$f3(x) = x^3 - 6x^2 + 4x - 12$$

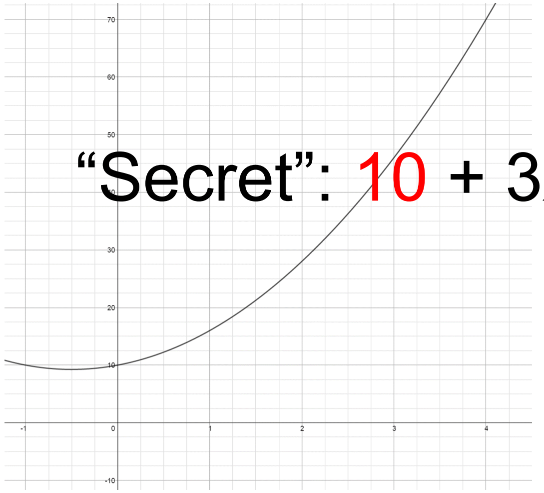
- Cubic function: Min 4 points

General: It takes k+1 points to defines a polynomial of degree k.

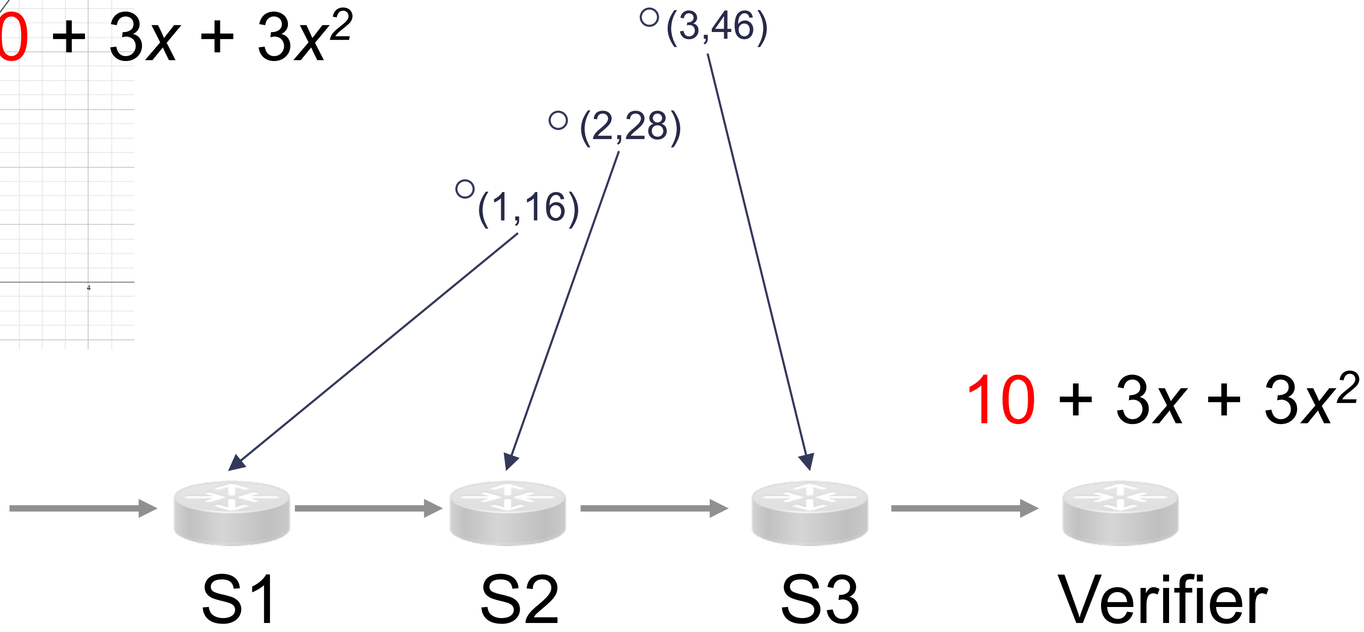
Credits: fbrockne@cisco.com

Solution Approach: Leveraging Shamir's Secret Sharing

Idea Concept



"Secret": $\color{red}{10} + 3x + 3x^2$



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Solution Approach: Leveraging Shamir’s Secret Sharing

- Outline :
  - Each service is given a point on the curve
  - When the packet travels through each service it collects these points
  - A verifier can reconstruct the curve using the collected points
  - If there are k+1 services and k+1 points chosen, then the verifier can construct
    k degree polynomial and verify.
  - The polynomial cannot be constructed if a few points are missed. Any lesser points means few services are missed!
- Concern: Operationally complex to configure and recycle so many curves and their respective points for each service function

Credits: fbrockne@cisco.com

Simpler & Faster with 2 Polynomials

- POLY-1 secret, constant per chain:
  - $a_1 + b_1 x + c_1 x^2 + \ldots$ (only known by verifier)
  - Each service gets a point on POLY-1 (for x = 1, 2, ...)
- POLY-2 public, with RND-2 random and per packet
  - *RND-2* $+ b_2 x + c_2 x^2 + \ldots$ (known by all services + verifier)
  - Each service generates a point on POLY-2 each time a packet crosses it (same *x* as in POLY-1)
- Each service adds the two points to get a point on POLY-3 and passes it to verifier by adding it to each packet.
- The verifier constructs POLY-3 from the points given by all the services and cross checks whether POLY-3 = POLY-1 + POLY-2
- *Computationally efficient: Only 3 additions and 1 multiplication per hop*
- *All operations are done in a finite field (modulo prime)*

POLY-1
Secret – Constant

+

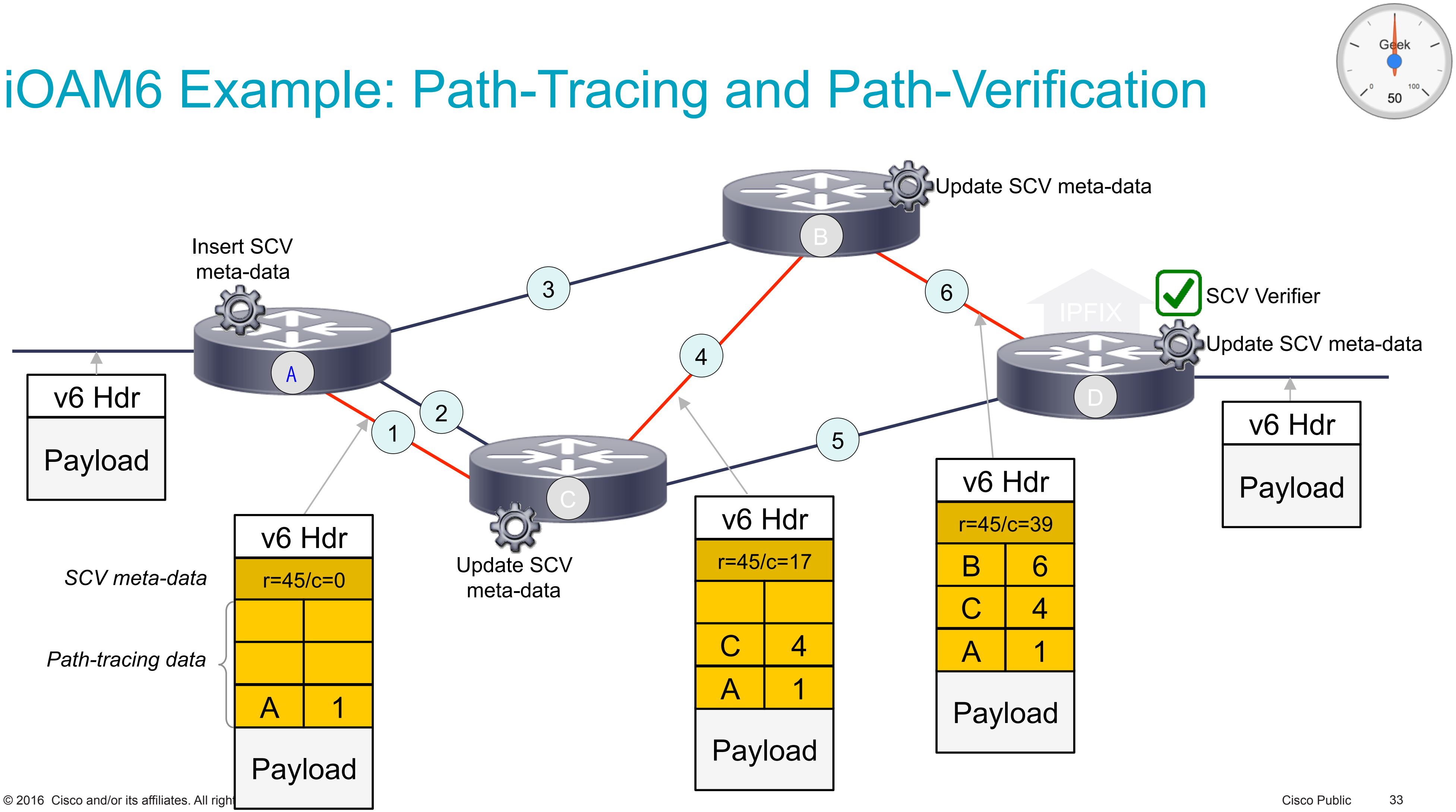
POLY-2
Public – Per Packet

=

POLY-3
Secret – Per Packet

Credits: fbrockne@cisco.com

iOAM6 Example: Path-Tracing and Path-Verification



Security Considerations

- An attacker bypassing few services, will miss adding a respective point on POLY-1 to corresponding point on POLY-2 , thus the verifier cannot construct POLY-3 for cross verification
- An attacker watching values, doing differential analysis across service functions (i.e. as the packets entering and leaving), cannot construct a point on POLY-1 as the operations are done over a finite field (i.e. modulo prime).
- Replay attacks could be avoided by carefully choosing POLY-2. It could be a timestamp concatenated with a random string.
- The proofs of correctness and security are based on Shamir's Secret Sharing Scheme .

Credits: fbrockne@cisco.com

Extension Headers Policy? Forward? Drop ?

Extension Header Security Policy

- White list approach for your traffic
  - Only allow the REQUIRED extension headers (and types), for example:
    - Fragmentation header
    - Routing header type 2 & destination option (when using mobile IPv6)
    - IPsec ☺ AH and ESP
    - And layer 4: ICMPv6, UDP, TCP, GRE, ...
  - If your firewall is capable:
    - Drop 1st fragment without layer-4 header
    - Drop routing header type 0
    - Drop/ignore hop-by-hop

Source: Tony Webster, Flickr

Extension Header Loss over the Internet

- End users SHOULD filter packets with extension headers
- But, what are your ISP and its transit provider doing to your packets?

Source: Paul Townsend, Flickr

- draft-gont-v6ops-ipv6-ehs-in-real-world
  - About 20-40% of packets with Ext Hdr are dropped over the Internet

Previous Extension Headers Research by Others

- IETF-88, Nov-2013, fgont-iepg-ietf88-ipv6-frag-and-eh.pdf
  - *“Fragmentation and Extension Header Support in the IPv6 Internet”*
  - Single origin, destination = Alexa top web sites (883 unique addr)
  - Ext header size: 8 bytes and 1024 bytes
  - Failure rate: 45%
- IETF-89, with Tim Chown: 60% packet drops
- IETF-90, Jul-2014, iepg-ietf90-ipv6-ehs-in-the-real-world-v2.0.pdf
  - *“IPv6 Extension Headers in the Real World v2.0”*
  - Origin: RIPE Atlas probes, destination = Alexa again
  - Ext header size: 8, 256, 512 and 1024 bytes
  - Failure rate: between 60% and 90%

Issues with Previous Experiments

- Destination: big web sites (Alexa)
- It is expected that destination drops what is unexpected
- Outdated by 9 months in early 2015
- Not testing about Routing Header (for segment routing)
- Not matching other empirical tests

Methodology of our study

1. Determine a set of IPv6 addresses to test :
   - From Alexa's Top 1 Million list
   - From IPv6 BGP-advertised prefixes
2. TCP Traceroute without EHs :
   - Send v6 packets with TCP payload to port 80 of the destination with varying TTL => Routers in the path answer with ICMPv6 Time Exceeded
3. TCP Traceroute with EHs:
   - Same thing but adding an Extension Header before the TCP payload
4. Analysing the traceroutes

Methodology of our research :
Step 1) Determining a set of IPv6 addresses to test

- From Alexa's Top 1 Million list :
  - Take those that have a AAAA record
  - … with a reachable IPv6 address in the AAAA record

- From BGP-advertised IPv6 prefixes
  - Address = [prefix]::1
  - Doesn't exist ? No problem, we are supposed to reach the AS -> Enough

Methodology of our research May 2015 : 2) TCP Traceroute with EHs

First, normal TCP traceroute without EH, then with EH

EH set :

- Destination Option Header
  16, 256, 512 bytes
- Hop-by-Hop Header
  16 bytes
- DO 16B + HbH 16B
- Routing Header type 4 (expected for Segment Routing)
- Fragment Header
  Normal and Atomic

EHs blocked by our ISP (so no result) :

- Hop-by-Hop Header
  256, 512 bytes
- Routing Header type 0 (deprecated)

Methodology of our study : Analysing the traceroutes

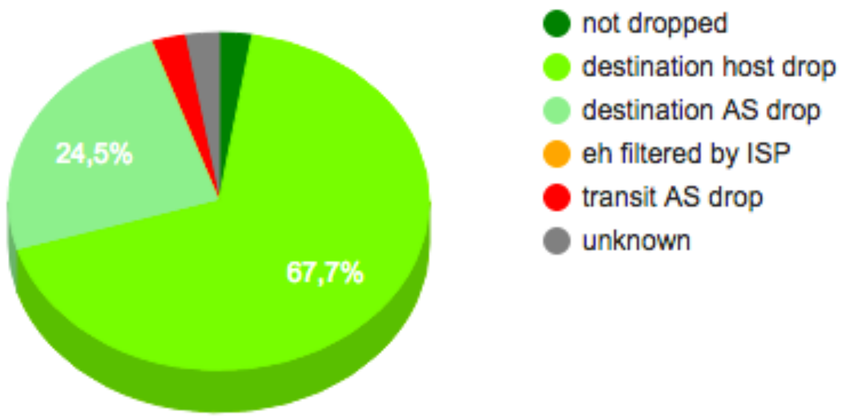
- Is it a problem ? Depends where it was dropped !
  - If dropped by the destination organization (host or same AS): Not a problem !
  - If dropped in transit: not cool…

- Where is the dropping node ?
  - If IP corresponds to some major IXPs, we look up the corresponding ASN by knowing the addressing logic, or in a database
  - Otherwise, normal GeoIP ASN lookup

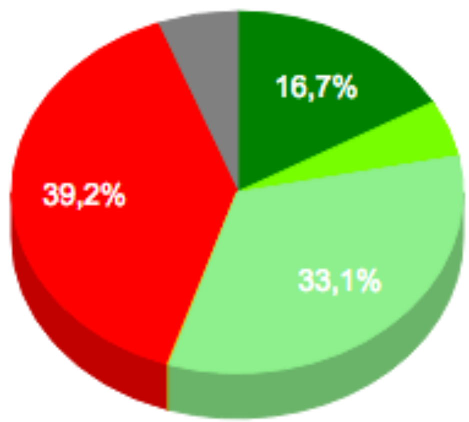
Results and analysis

- Drop rates depend on the Extension Header

D.O. 16B

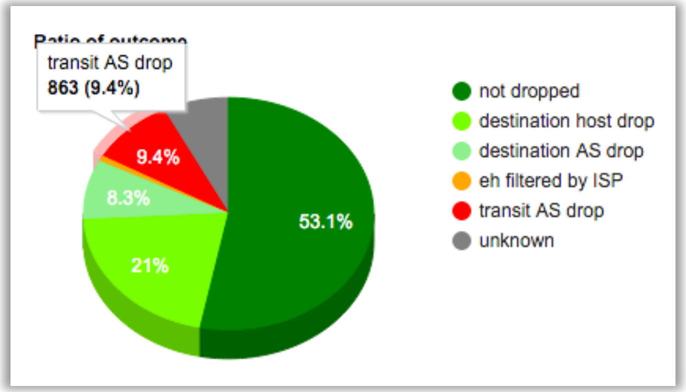


HbH 16B

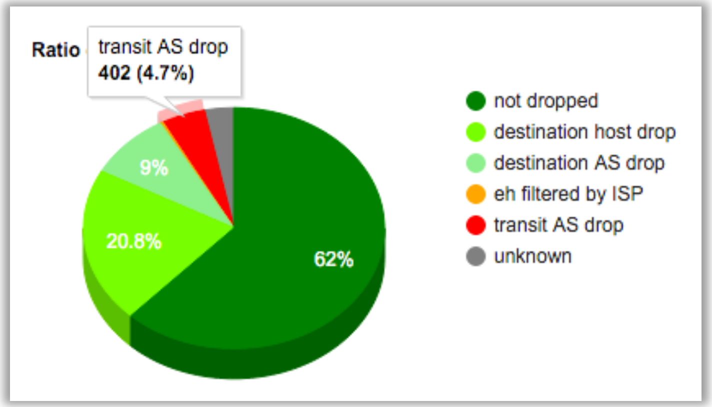


For Alexa

Things Keeps Improving Though



BGP in Spring 2015



BGP in Spring 2016

- Current research by Polytechnique Paris (Mehdi Kouhen) and Cisco (Eric Vyncke)
  - And VM provided by Sander Steffann
- https://btv6.vyncke.org/exthdr/index.php?ds=bgp2016&t=fh (work in progress!)
- http://evyncke.go6lab.si/exthdr/index.php

Summary

Summary

- Extension headers are useful to extend IPv6
  - Good old IPsec
  - New functions: segment routing, iOAM
- Let's not be naïve though
  - Do we need fragments?
  - Transit providers: do not harm extension headers
  - Internet edge: use a strict white list approach

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