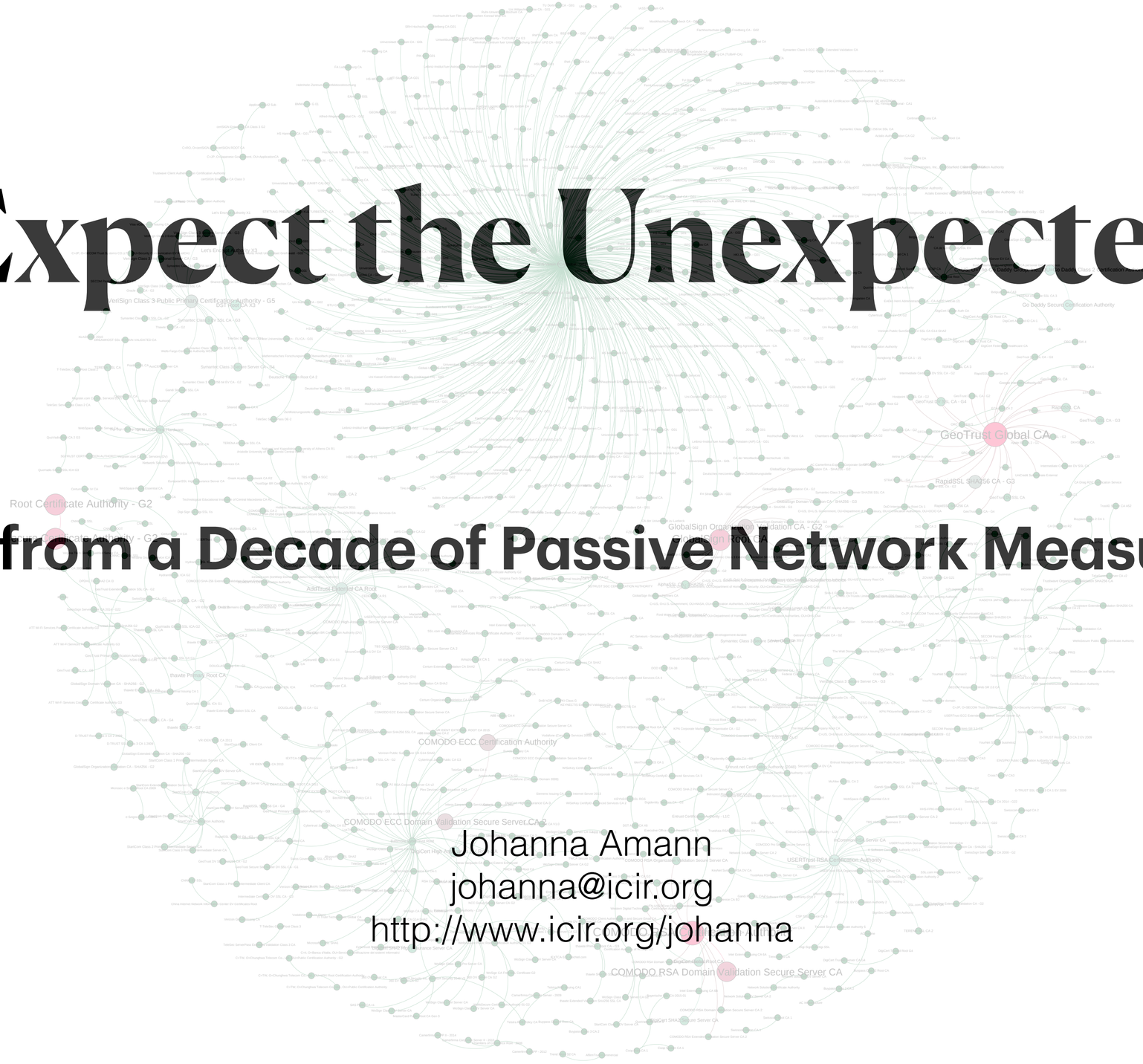
Expect the Unexpected

Lessons from a Decade of Passive Network Measurements



Johanna Amann
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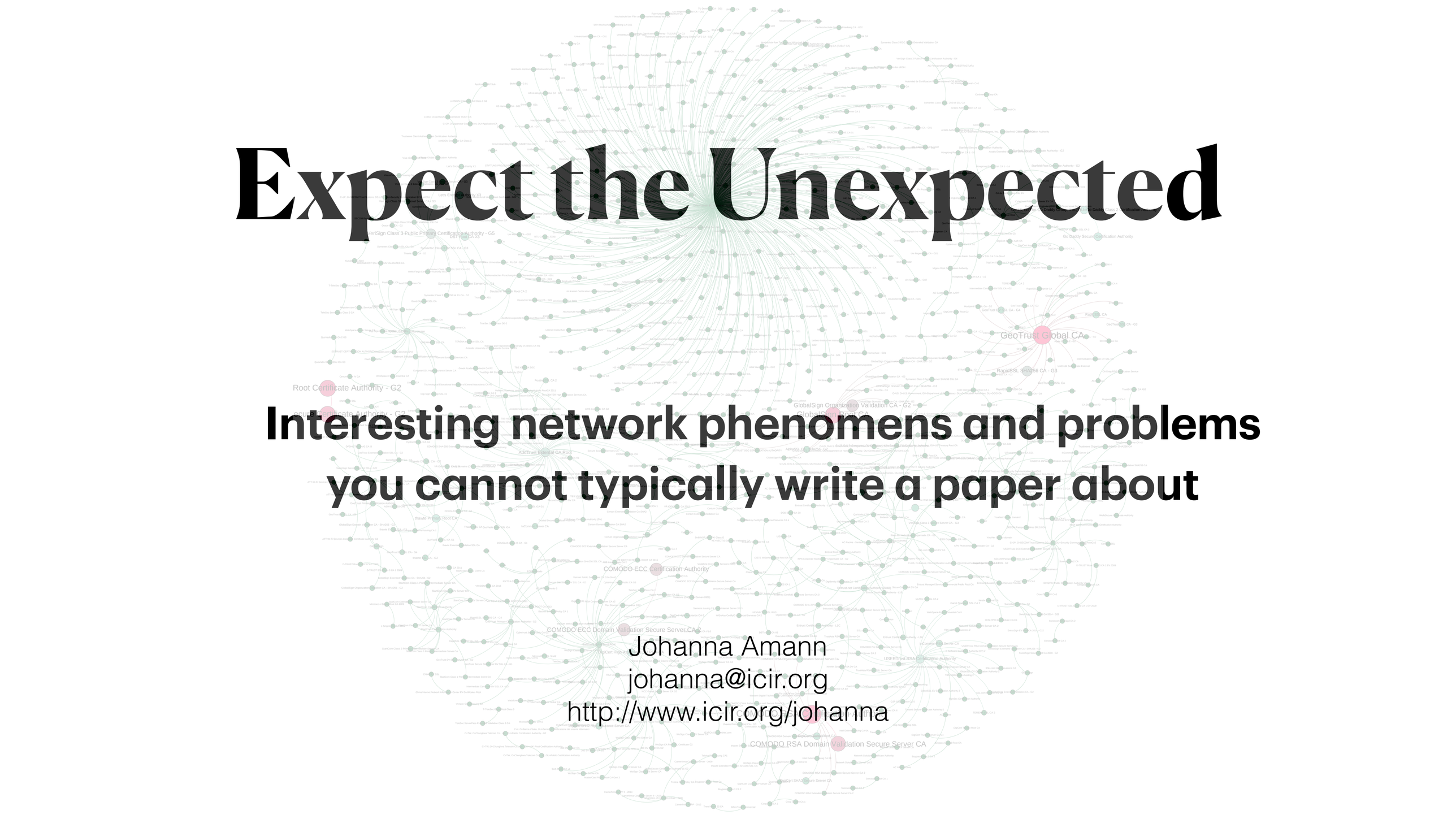
http://www.icir.org/johanna

Who am I?


ICSI
INTERNATIONAL
COMPUTER SCIENCE
INSTITUTE


corelight


BERKELEY LAB



Expect the Unexpected

Interesting network phenomens and problems you cannot typically write a paper about

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Part 1

Passive Network Measurements


857


2011

PRESS RELEASE
June 6, 2011

Apple Introduces iCloud

Free Cloud Services Beyond Anything Offered to Date

SAN FRANCISCO—June 6, 2011—Apple® today introduced iCloud®, a breakthrough set of free new cloud services that work seamlessly with applications on your iPhone®, iPad®, iPod touch®, Mac® or PC to automatically and wirelessly store your content in iCloud and automatically and wirelessly push it to all your devices. When anything changes on one of your devices, all of your devices are wirelessly updated almost instantly.

PRESS RELEASE
June 6, 2011

Apple Introduces iCloud

Free Cloud Service

SAN FRANCISCO—Jun
a breakthrough set of fr
with applications on you
automatically and wirele
automatically and wirele
changes on one of your
updated almost instantl

Google

Official Blog

Insights from Googlers into our products, technology, and the Google culture

Introducing the Google+ project: Real-life sharing, rethought for the web

June 28, 2011

Update: *For our international readers, this post is also available in French, German, Italian, Japanese, Portuguese, Russian and Spanish. - Ed.*

Among the most basic of human needs is the need to connect with others. With a smile, a laugh, a whisper or a cheer, we connect with others every single day.

PRESS RELEASE
June 6, 2011

Apple Introduces iCloud

Free Cloud Service

SAN FRANCISCO—Jun
a breakthrough set of fr
with applications on you
automatically and wirele
automatically and wirele
changes on one of your
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Google

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Introducing the
for the web

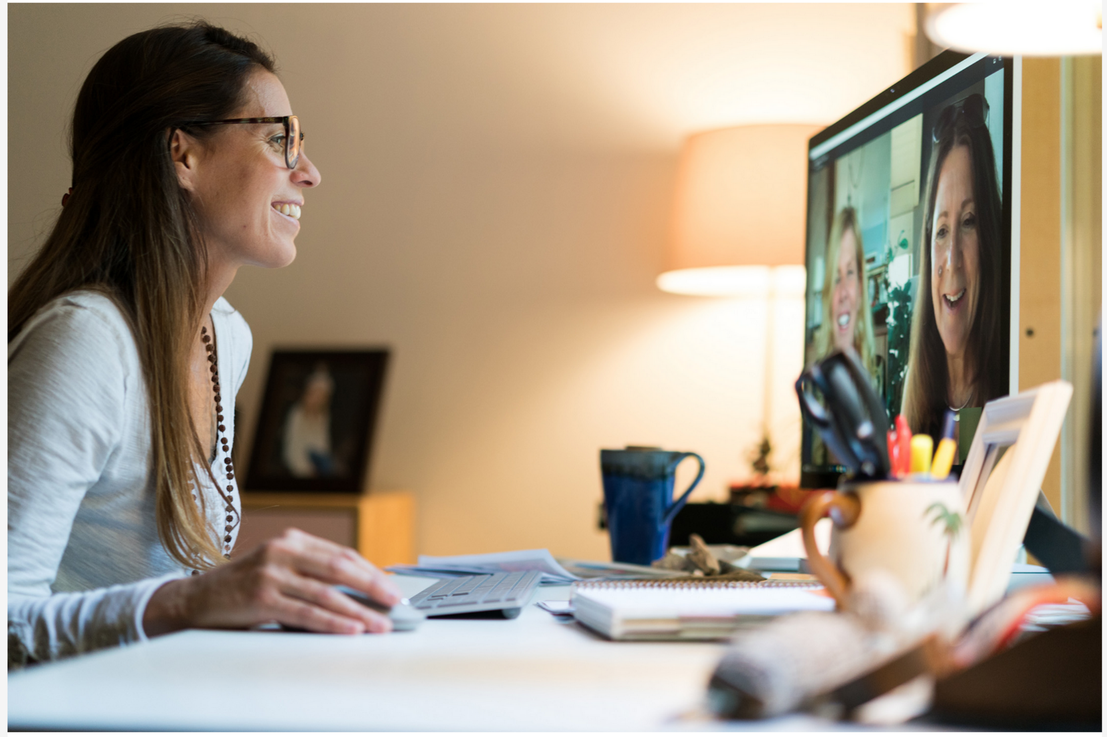
June 28, 2011

Update: *For our interna*

Italian, *Japanese*, *Portu*

Among the most basic
smile, a laugh, a whisp

Microsoft acquires Skype



Microsoft purchased Skype for $8.5 billion, deepening the company's longstanding focus on real-time video and voice communications, and providing new market opportunities serving Skype's 160-plus million active users

PRESS RELEASE
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Apple Introduces iCloud

Free Cloud Service

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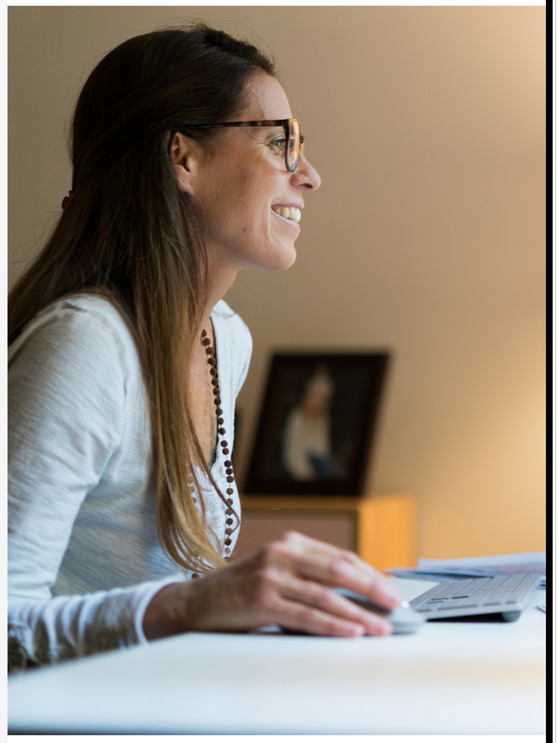


Microsoft purchased Skype for $8.5 billion, deepening the
voice communications, and providing new market opport

Spotify

This article is more than **10 years old**

Spotify announces launch in the US

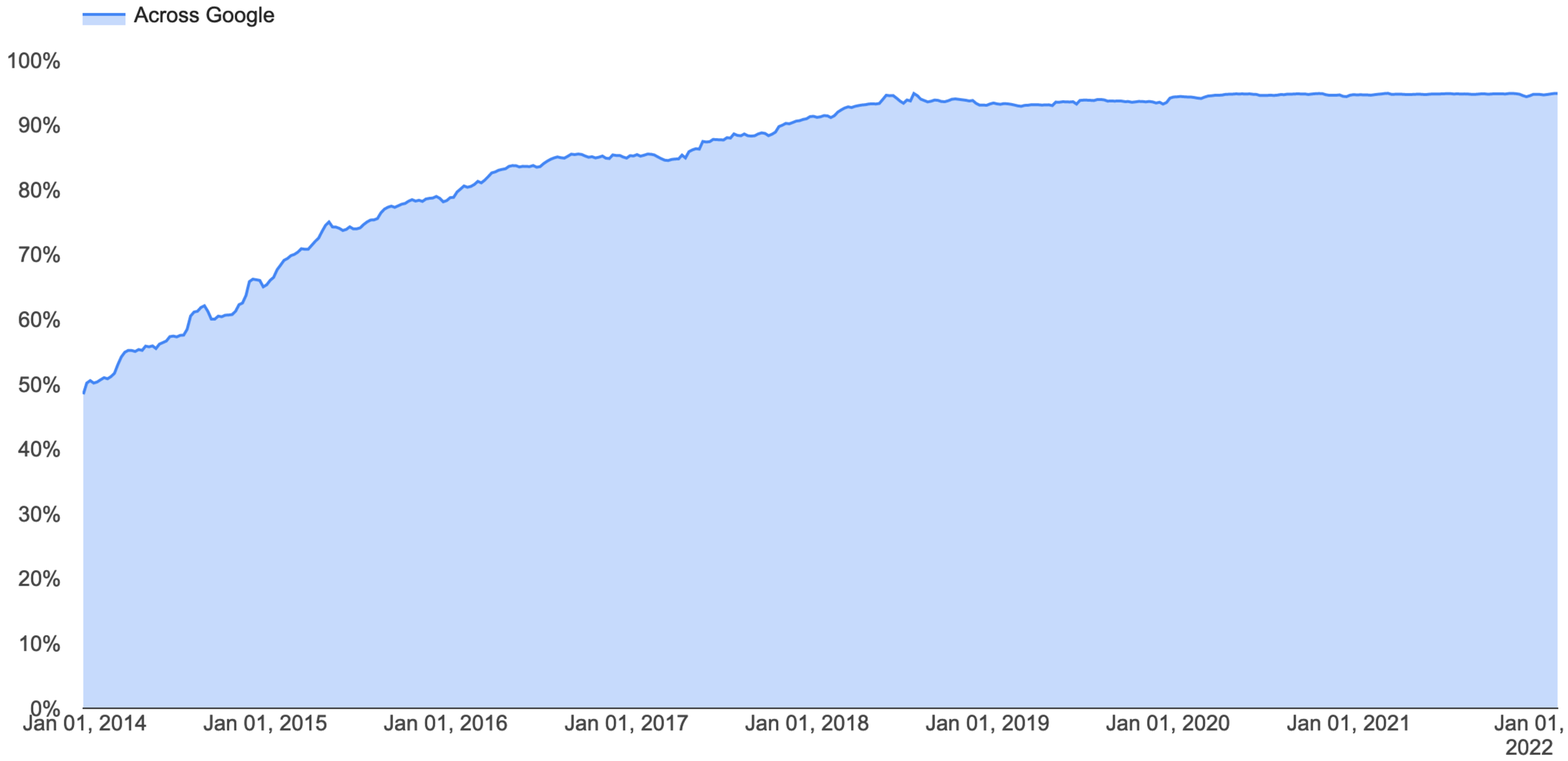
Swedish music streaming service expands beyond Europe for first time after two years of negotiations with record companies

Jemima Kiss
@jemimakiss
Thu 14 Jul 2011 01.46 BST

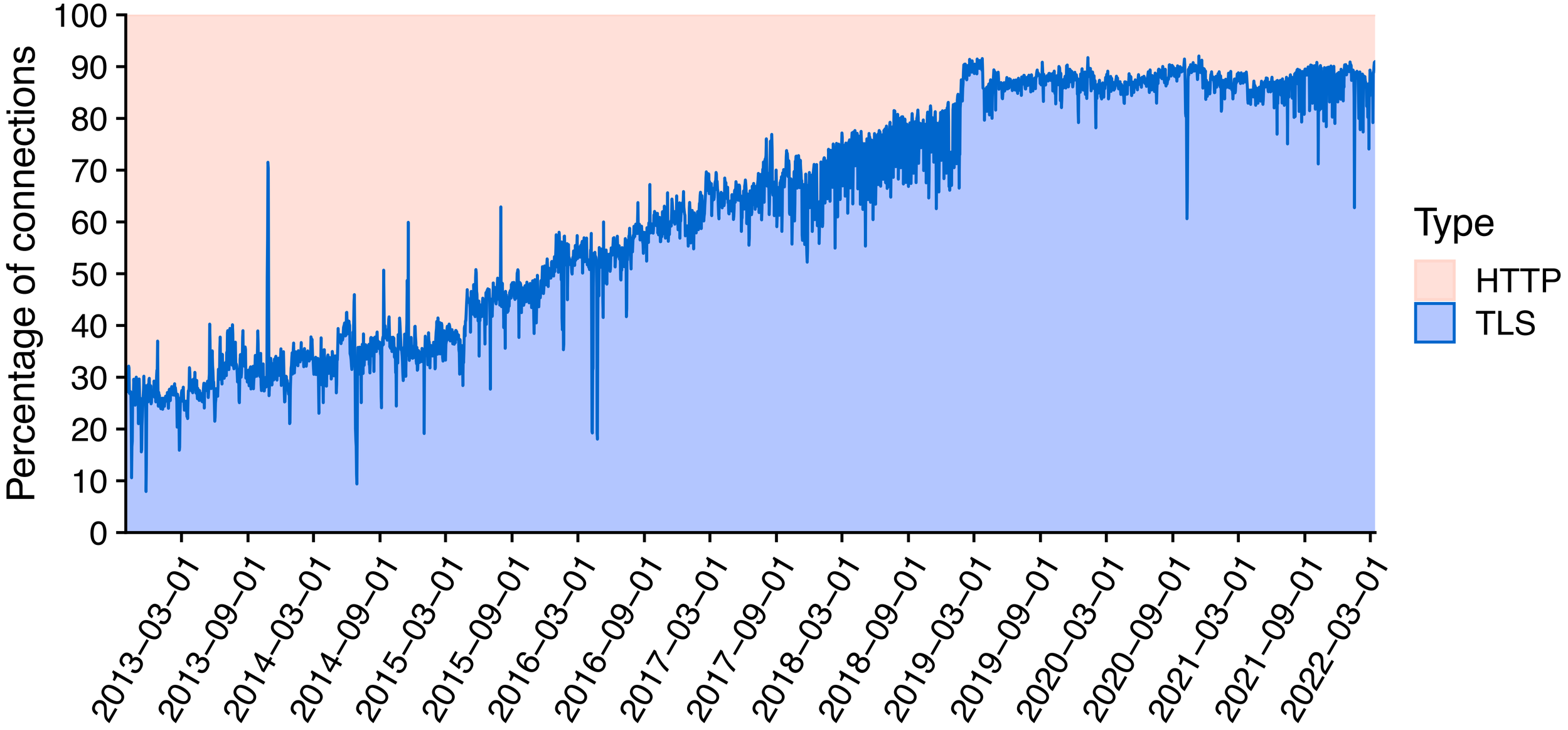
Daniel Ek, co-founder and CEO of Spotify: the company has been valued at around $1bn. Photograph: Rasmus Andersson/Spotify

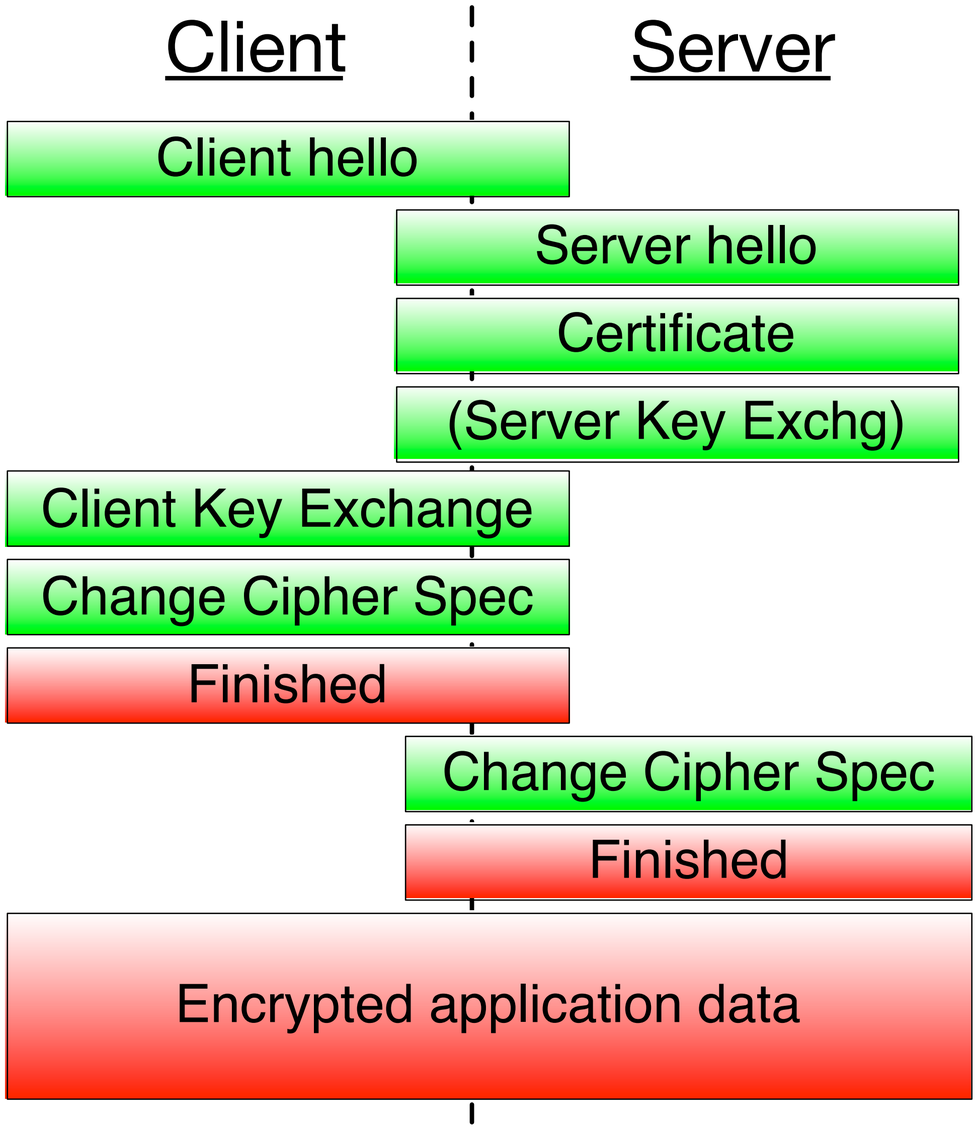
It has taken two years of intense wrangling with record companies and triggered wave after wave of speculation about future business models for the industry - now Spotify, the Swedish streaming music service, has finally announced that it will launch in the world's biggest music market, the US, on Thursday.

Encrypted Traffic across Google

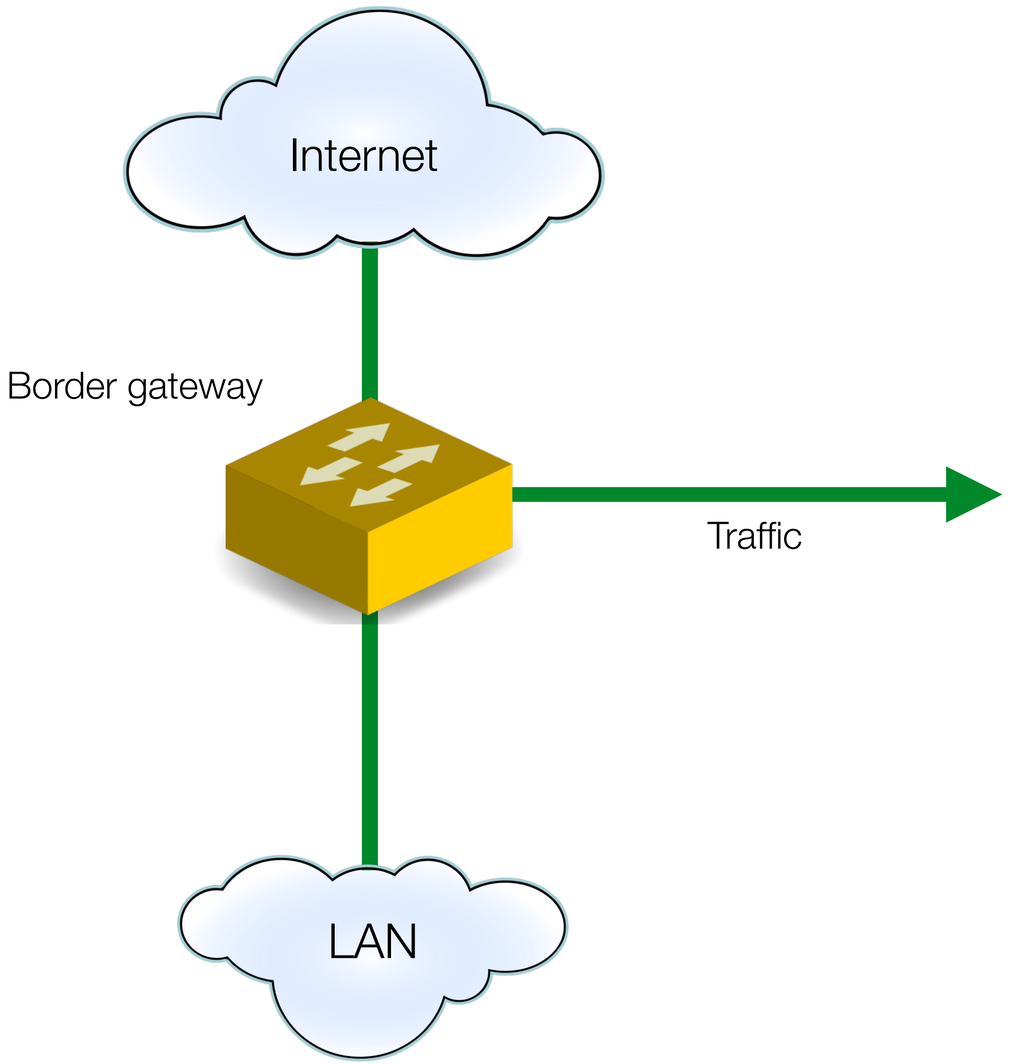


Encrypted traffic at Berkeley Lab




Client
Server
Client hello
Server hello
Certificate
(Server Key Exchg)
Client Key Exchange
Change Cipher Spec
Finished
Change Cipher Spec
Finished
Encrypted application data

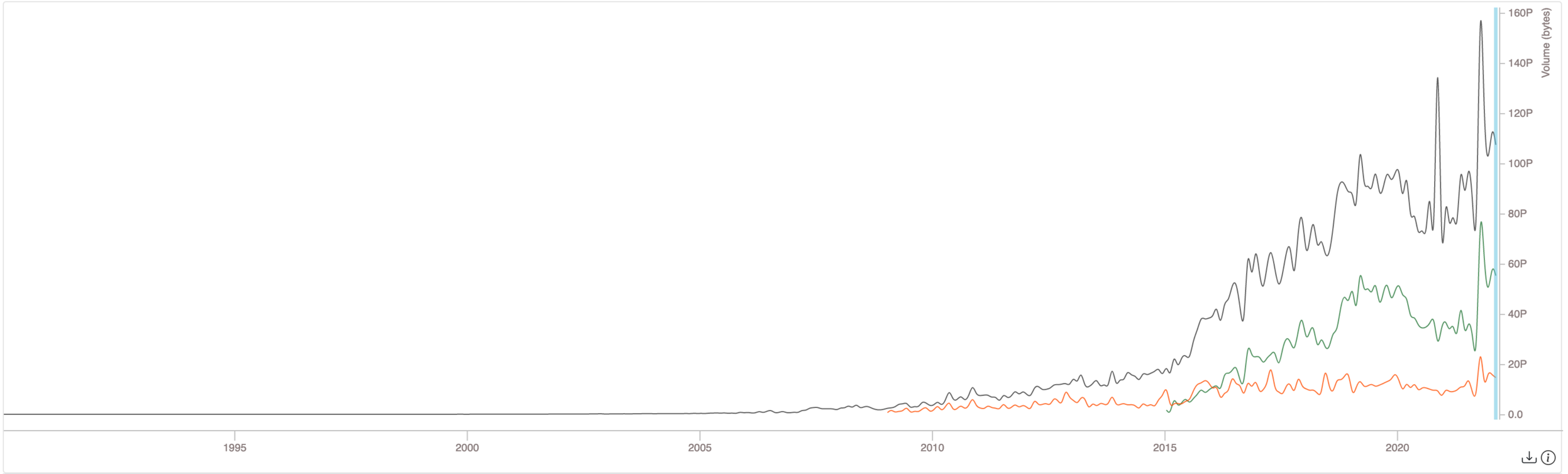
Typical Network Monitoring Setup



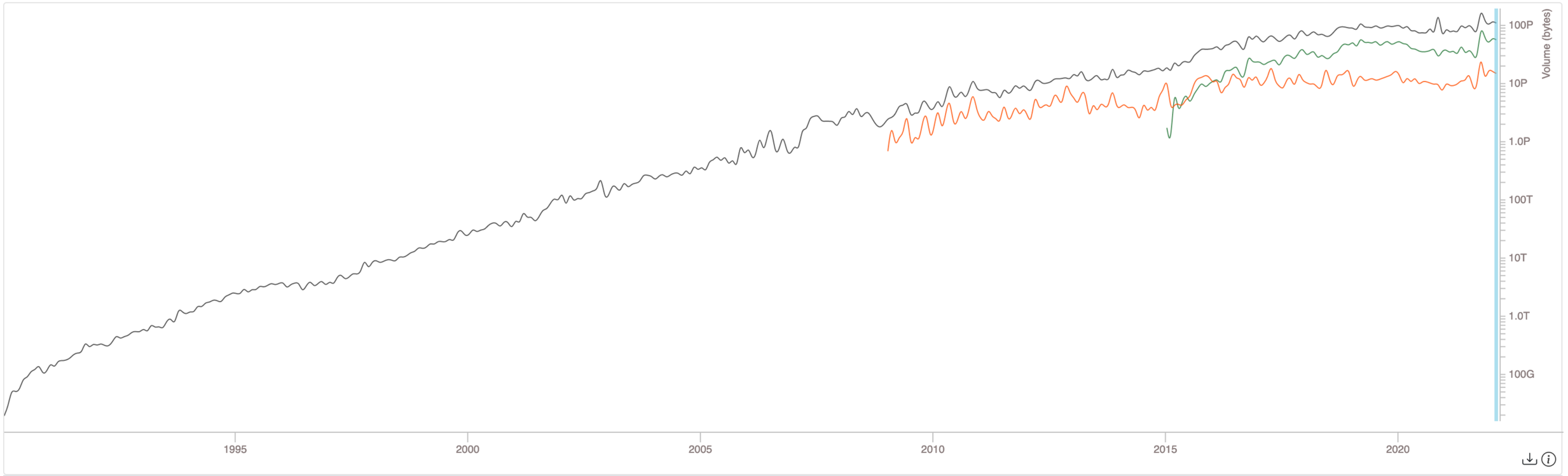
zeek

SURICATA

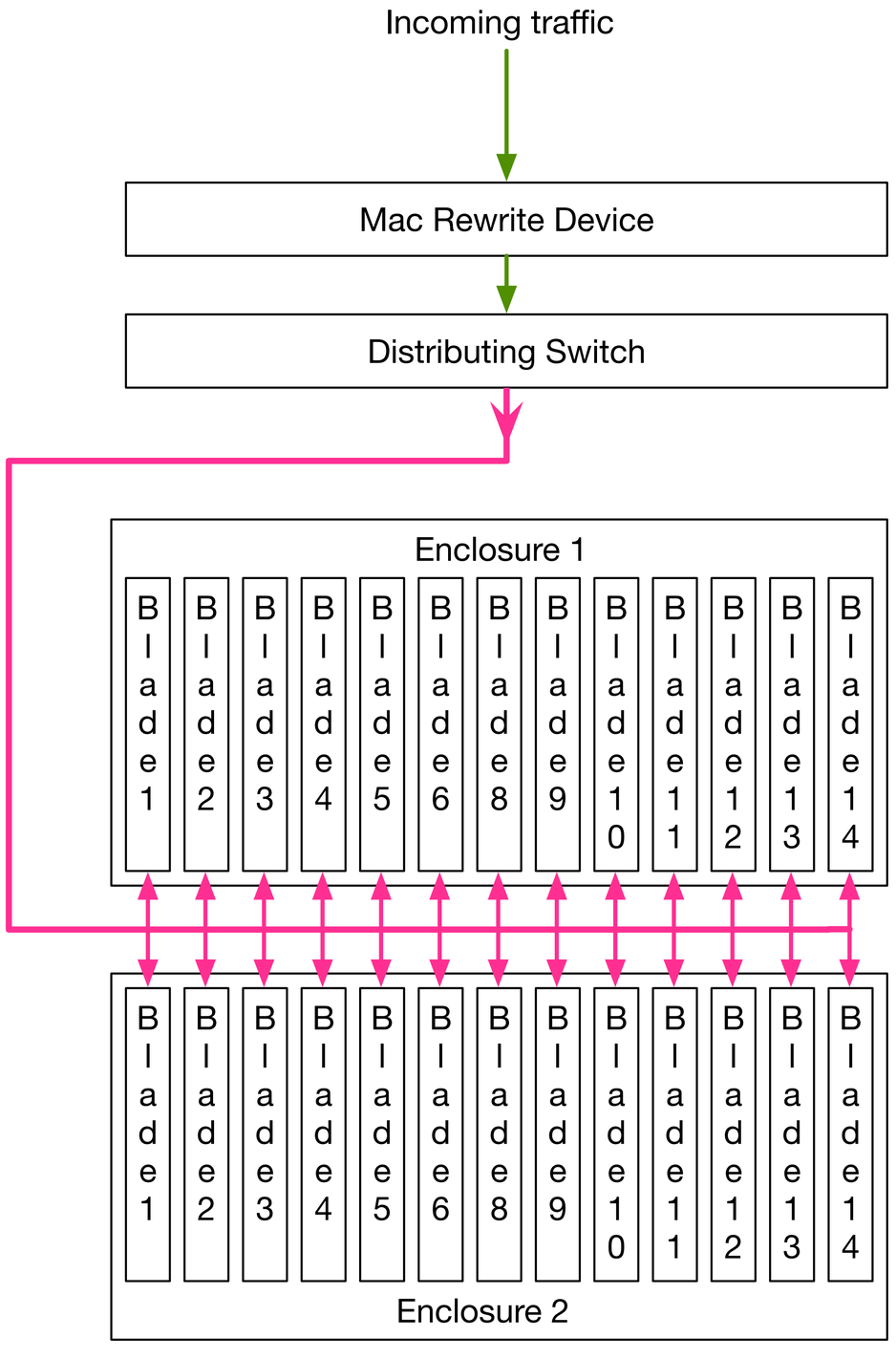
SNORT™

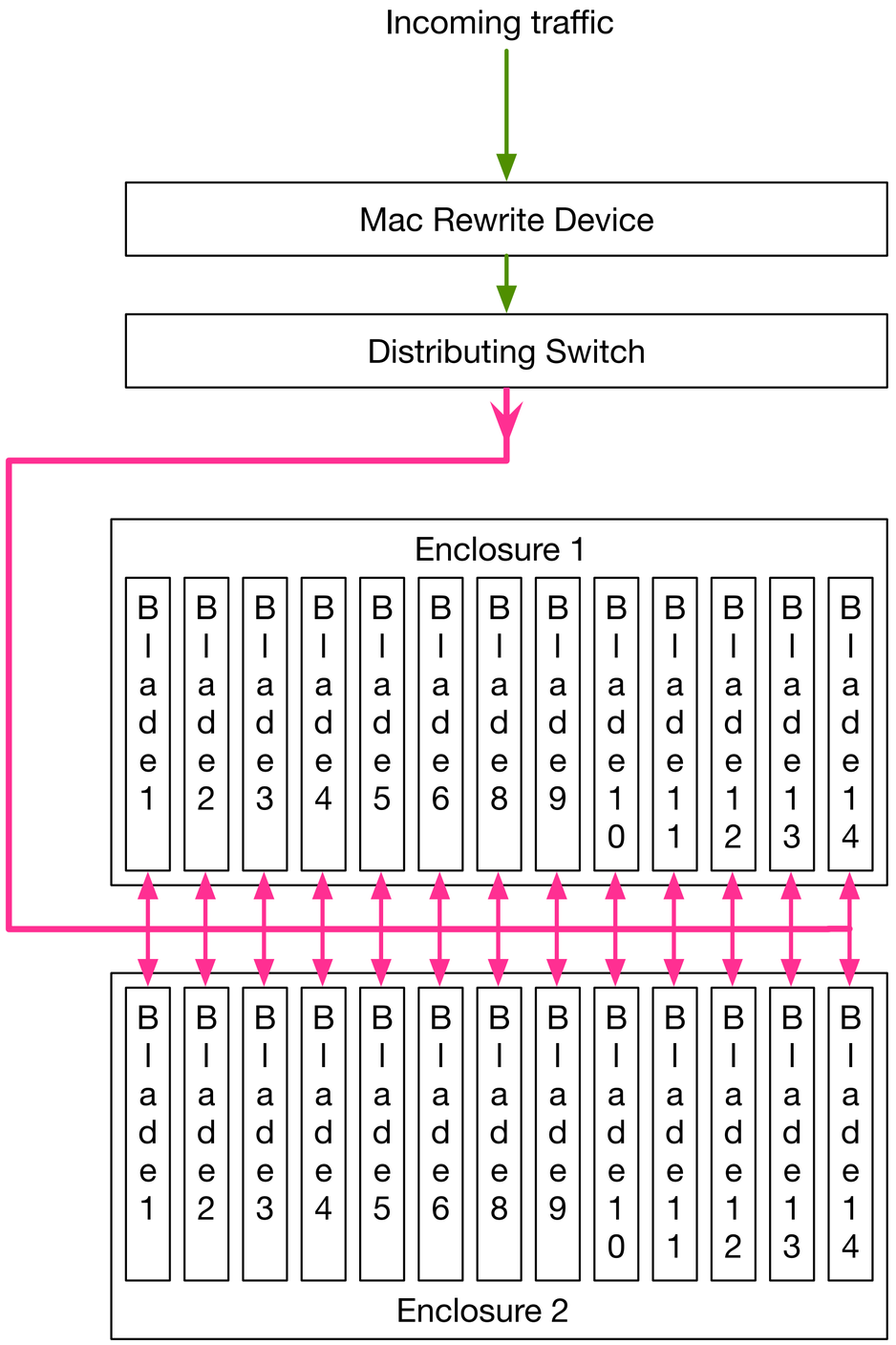


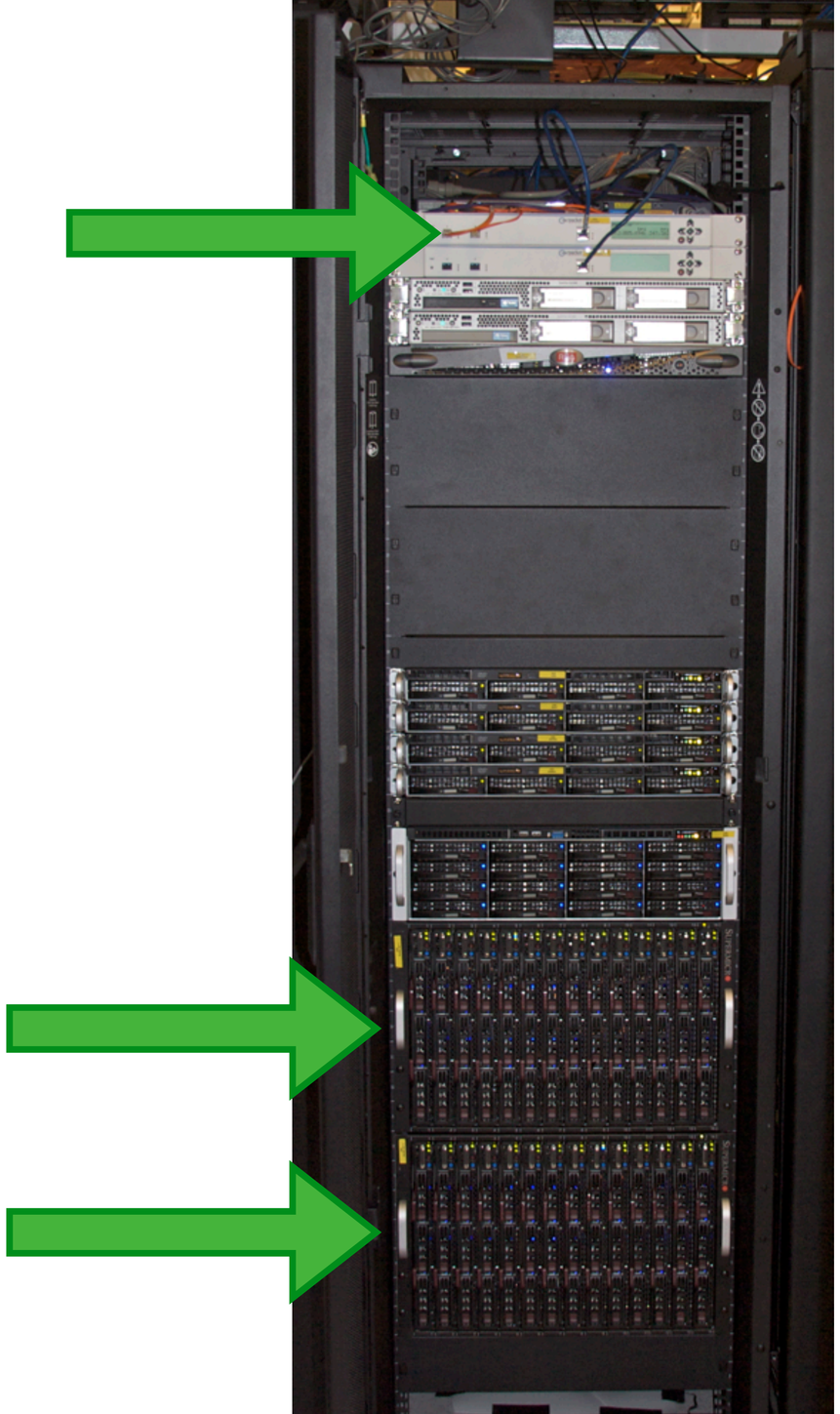
Source: https://my.es.net/

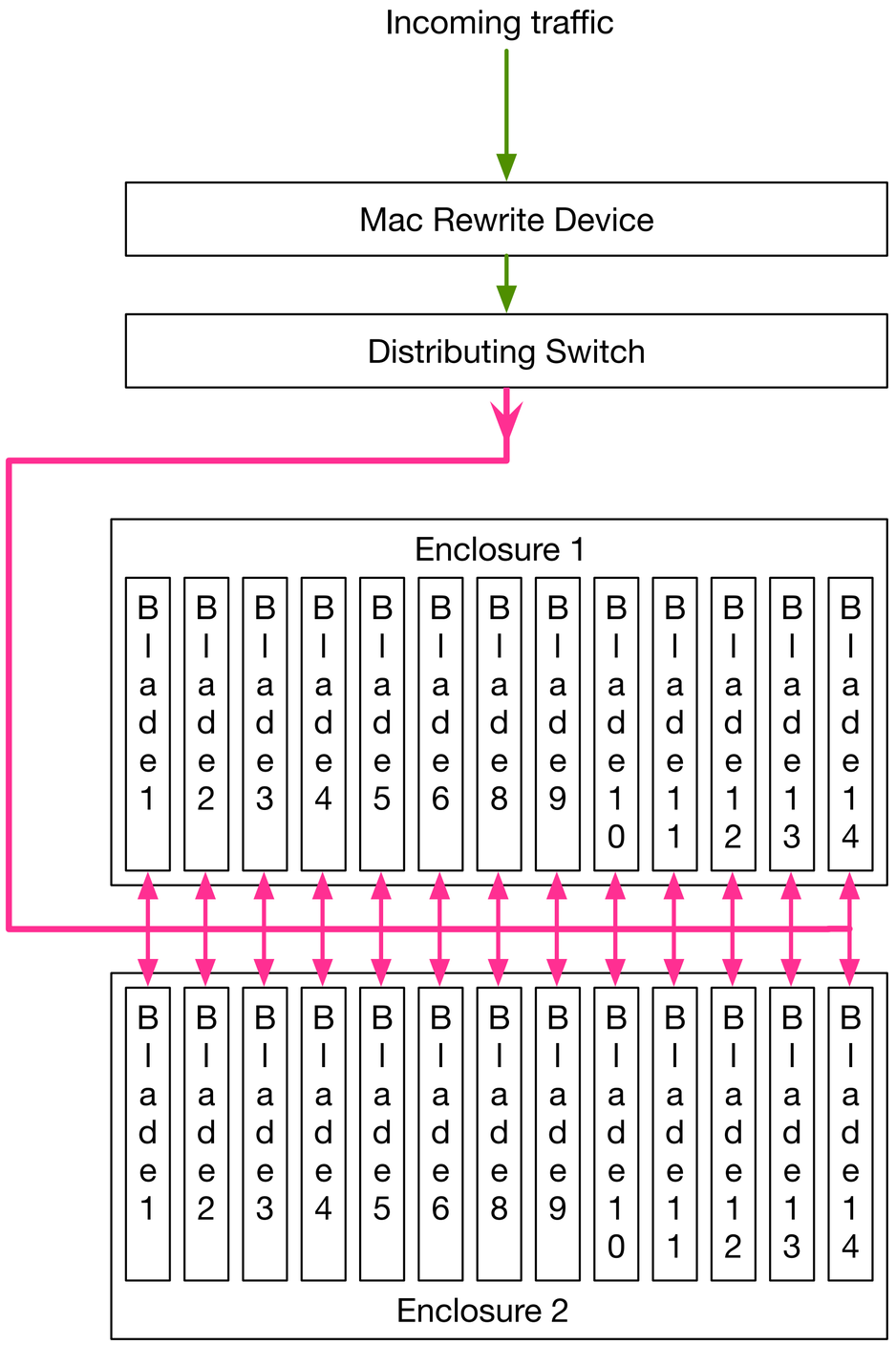


Source: https://my.es.net/


Incoming traffic
Mac Rewrite Device
Distributing Switch
Enclosure 1
Blade1
Blade2
Blade3
Blade4
Blade5
Blade6
Blade8
Blade9
Blade10
Blade11
Blade12
Blade13
Blade14
Blade1
Blade2
Blade3
Blade4
Blade5
Blade6
Blade8
Blade9
Blade10
Blade11
Blade12
Blade13
Blade14
Enclosure 2


Incoming traffic
Mac Rewrite Device
Distributing Switch
Enclosure 1
Blade1
Blade2
Blade3
Blade4
Blade5
Blade6
Blade8
Blade9
Blade10
Blade11
Blade12
Blade13
Blade14
Blade1
Blade2
Blade3
Blade4
Blade5
Blade6
Blade8
Blade9
Blade10
Blade11
Blade12
Blade13
Blade14
Enclosure 2




Incoming traffic
Mac Rewrite Device
Distributing Switch
Enclosure 1
Blade1
Blade2
Blade3
Blade4
Blade5
Blade6
Blade8
Blade9
Blade10
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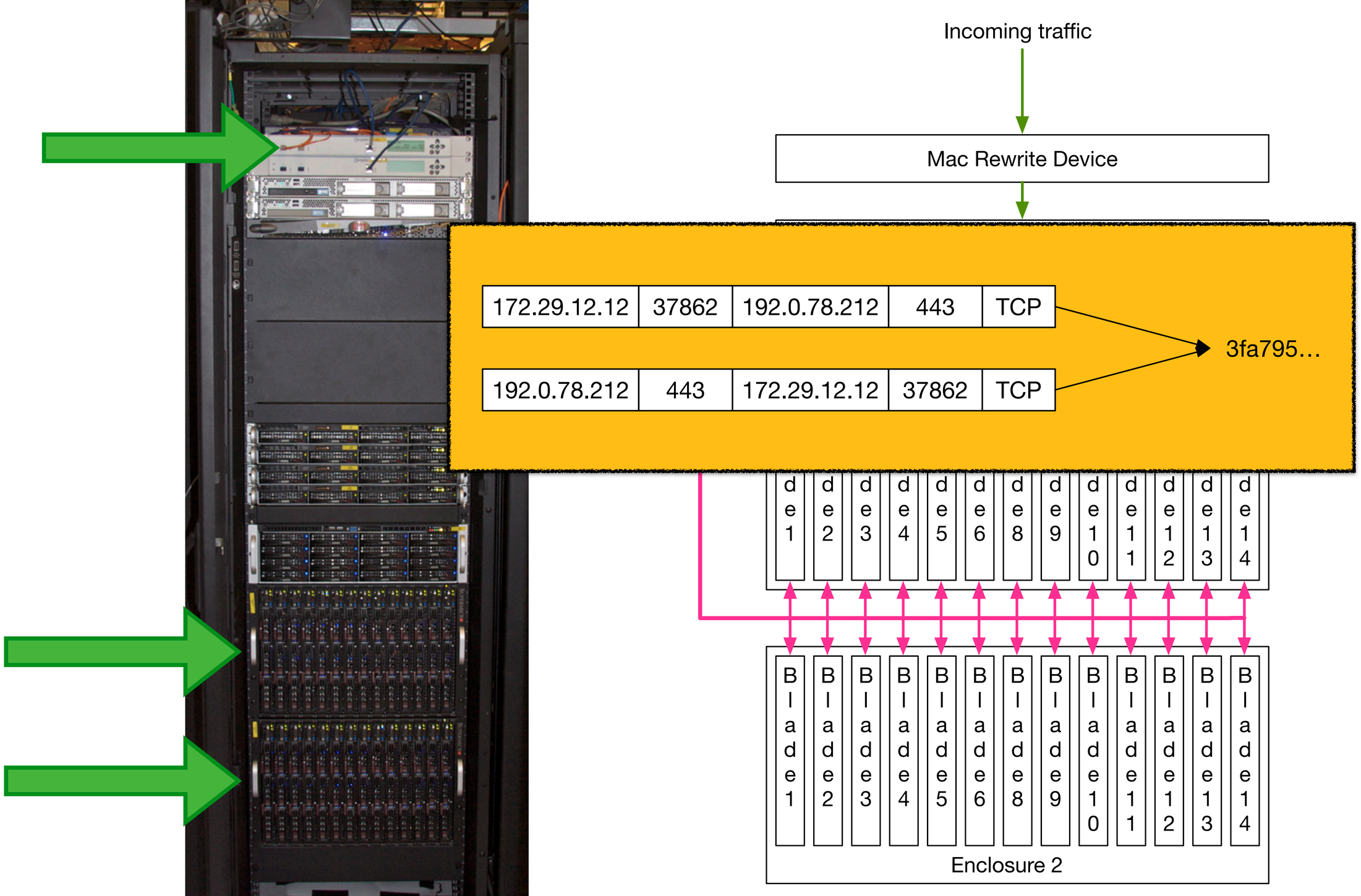
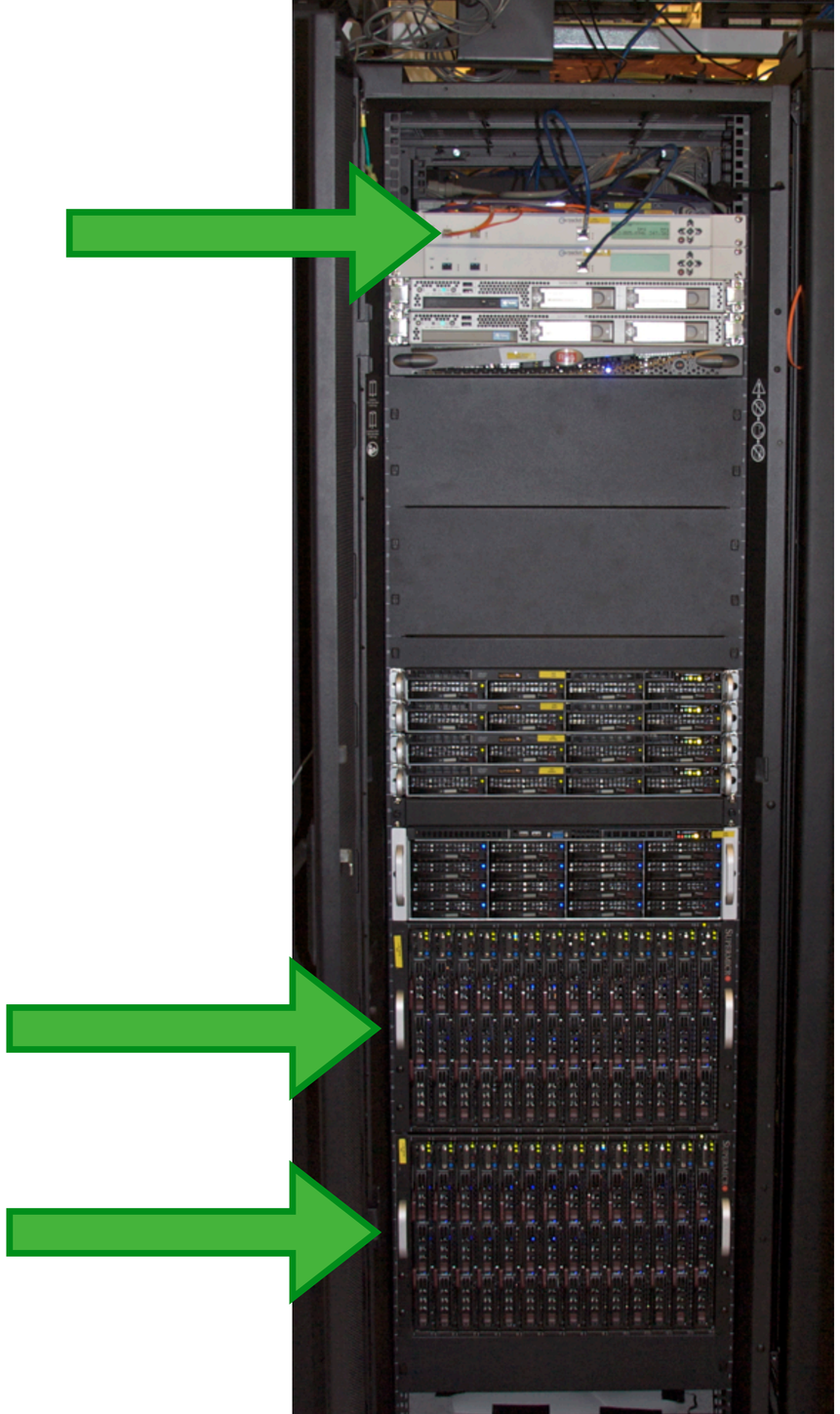
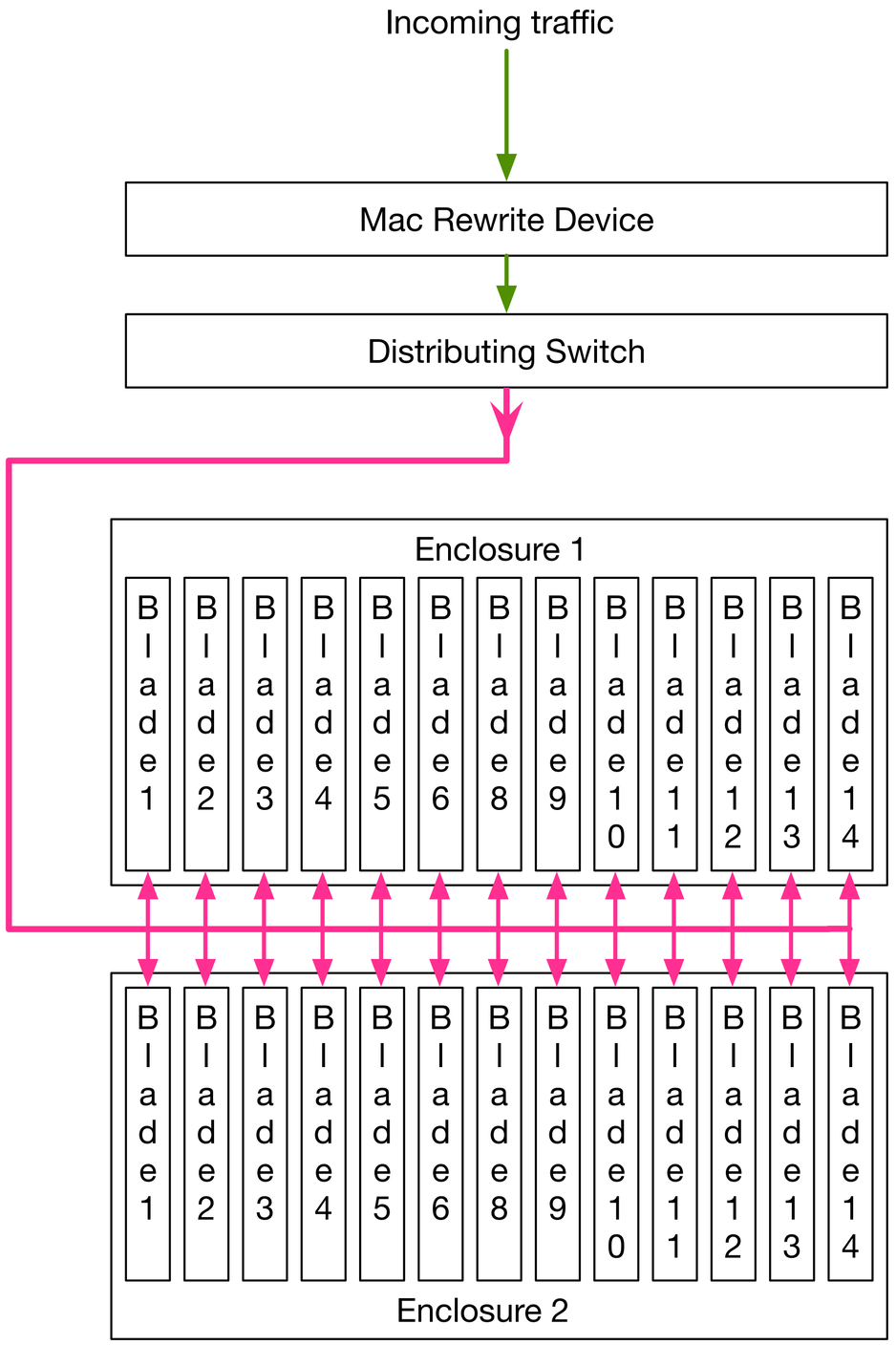
Blade6
Blade8
Blade9
Blade10
Blade11
Blade12
Blade13
Blade14
Enclosure 2


Incoming traffic
Mac Rewrite Device
172.29.12.12
37862
192.0.78.212
443
TCP
192.0.78.212
443
172.29.12.12
37862
TCP
3fa795…
de1
de2
de3
de4
de5
de6
de8
de9
de10
de11
de12
de13
de14
Blade1
Blade2
Blade3
Blade4
Blade5
Blade6
Blade8
Blade9
Blade10
Blade11
Blade12
Blade13
Blade14
Enclosure 2




Incoming traffic
Mac Rewrite Device
Distributing Switch
Enclosure 1
Blade1
Blade2
Blade3
Blade4
Blade5
Blade6
Blade8
Blade9
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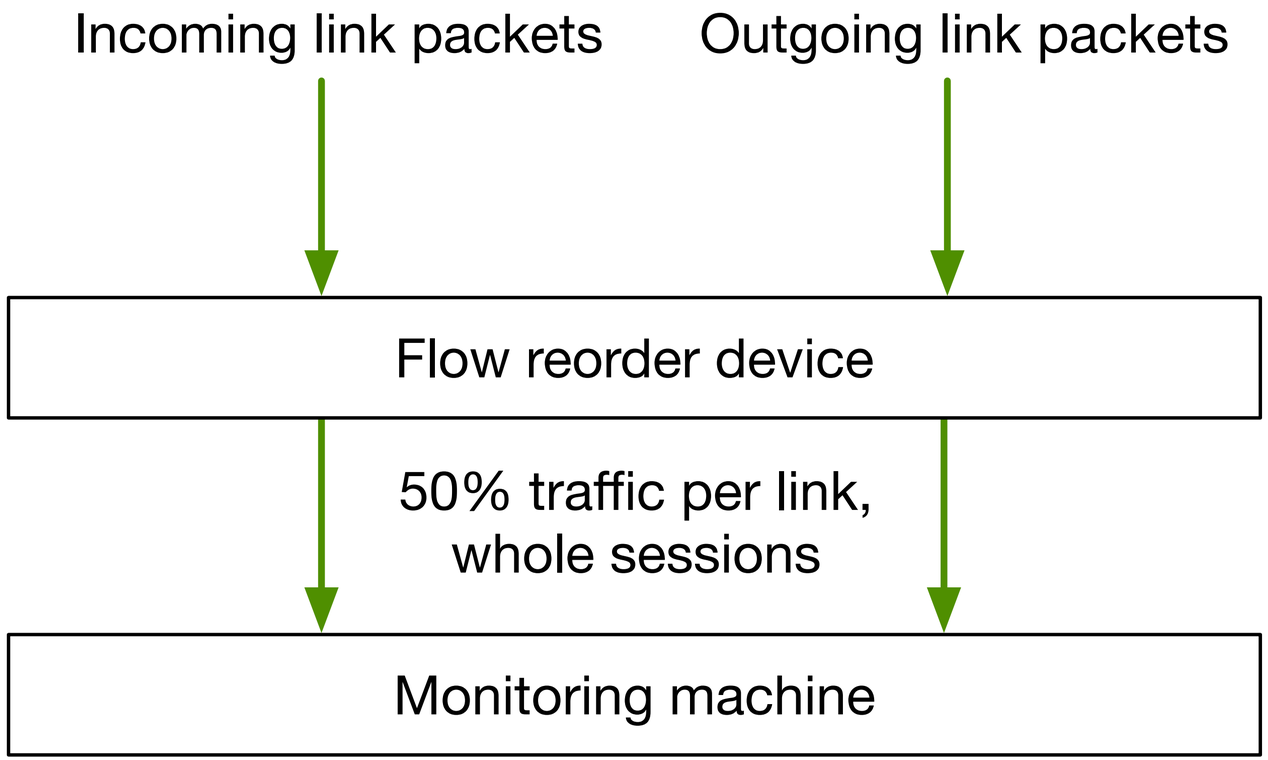
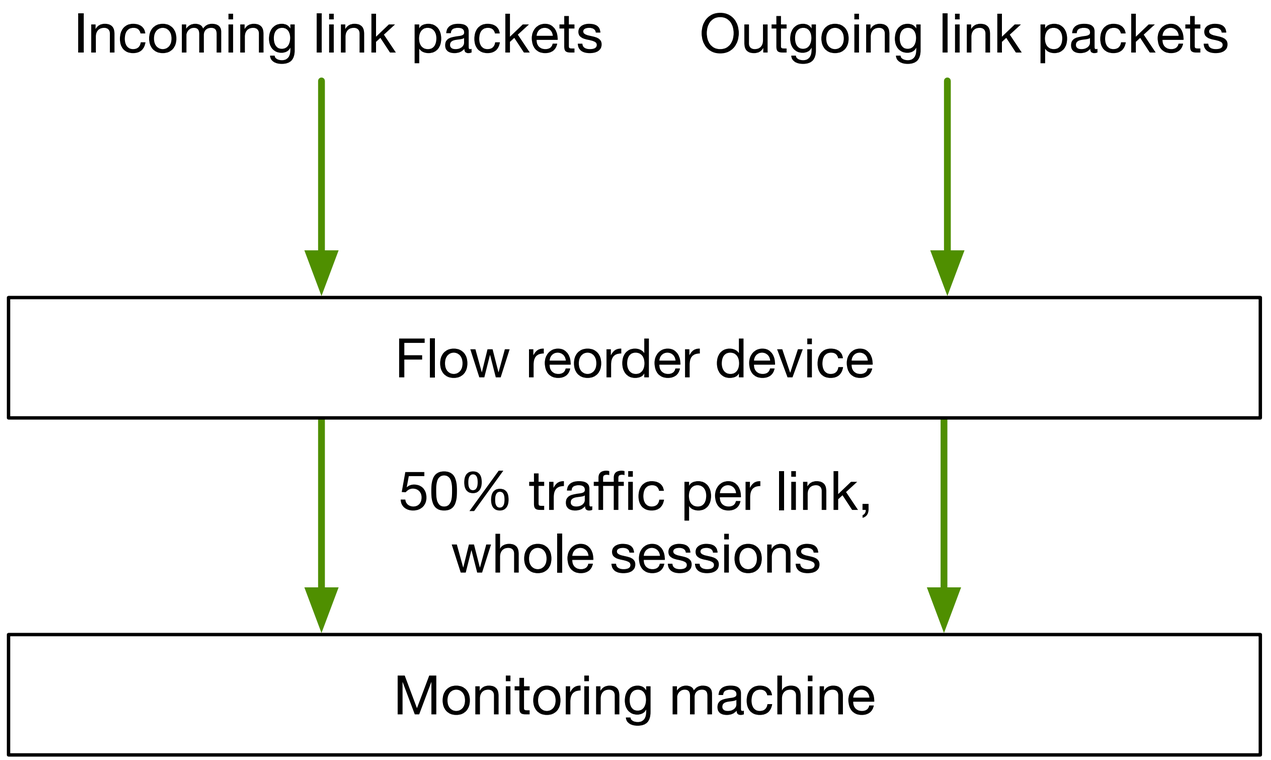
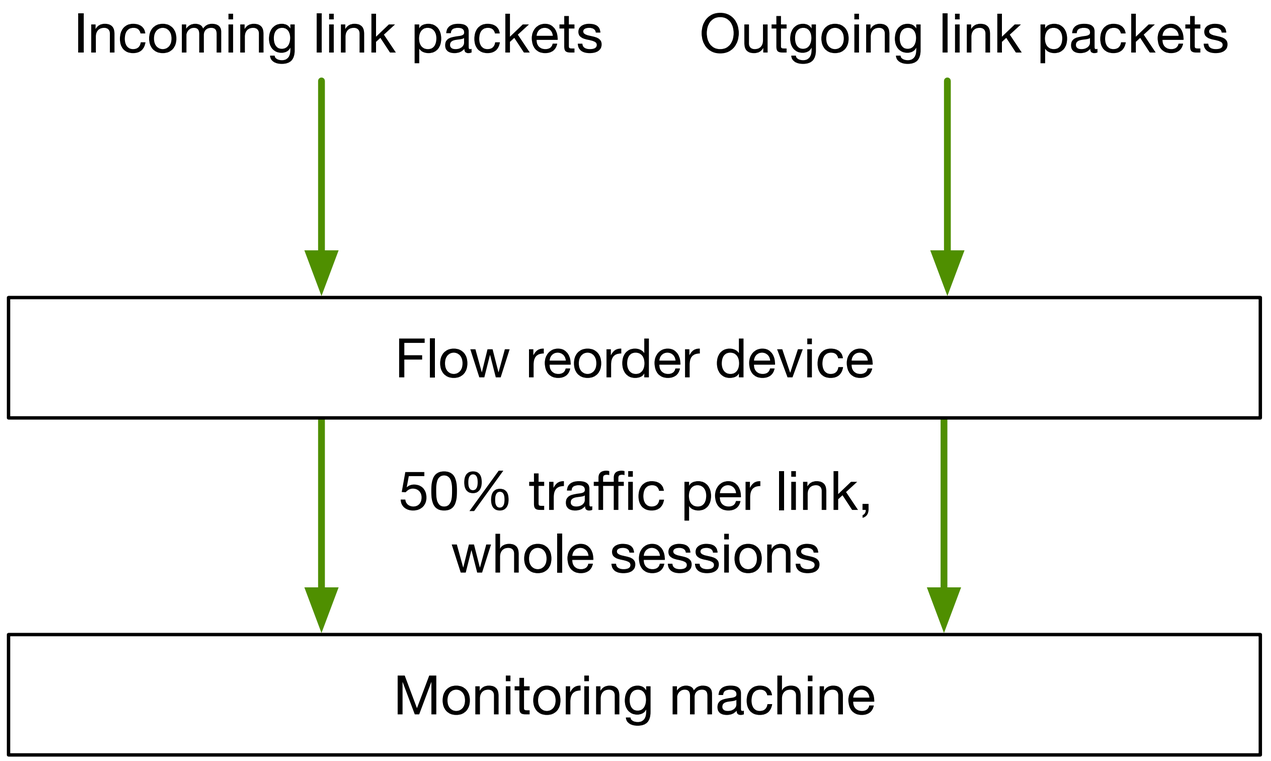
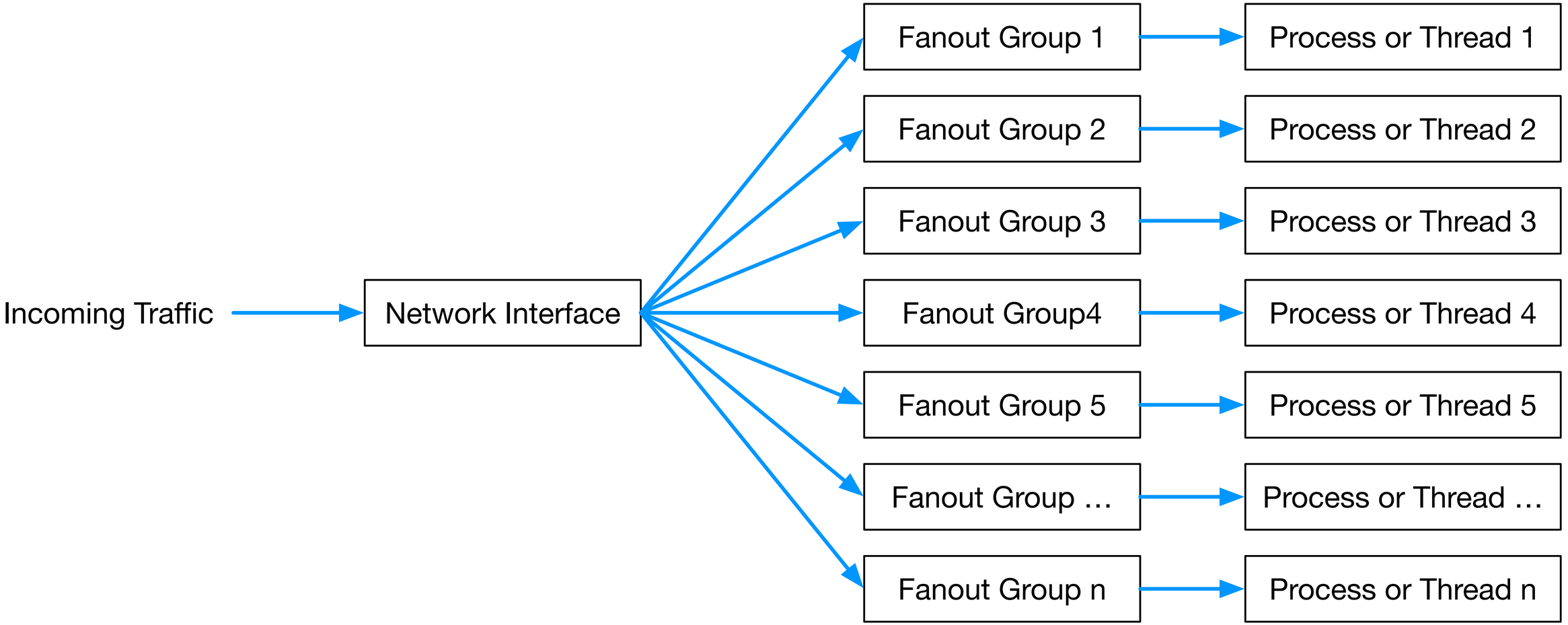
Blade14
Blade1
Blade2
Blade3
Blade4
Blade5
Blade6
Blade8
Blade9
Blade10
Blade11
Blade12
Blade13
Blade14
Enclosure 2


Incoming link packets
Outgoing link packets
Flow reorder device
50% traffic per link,
whole sessions
Monitoring machine

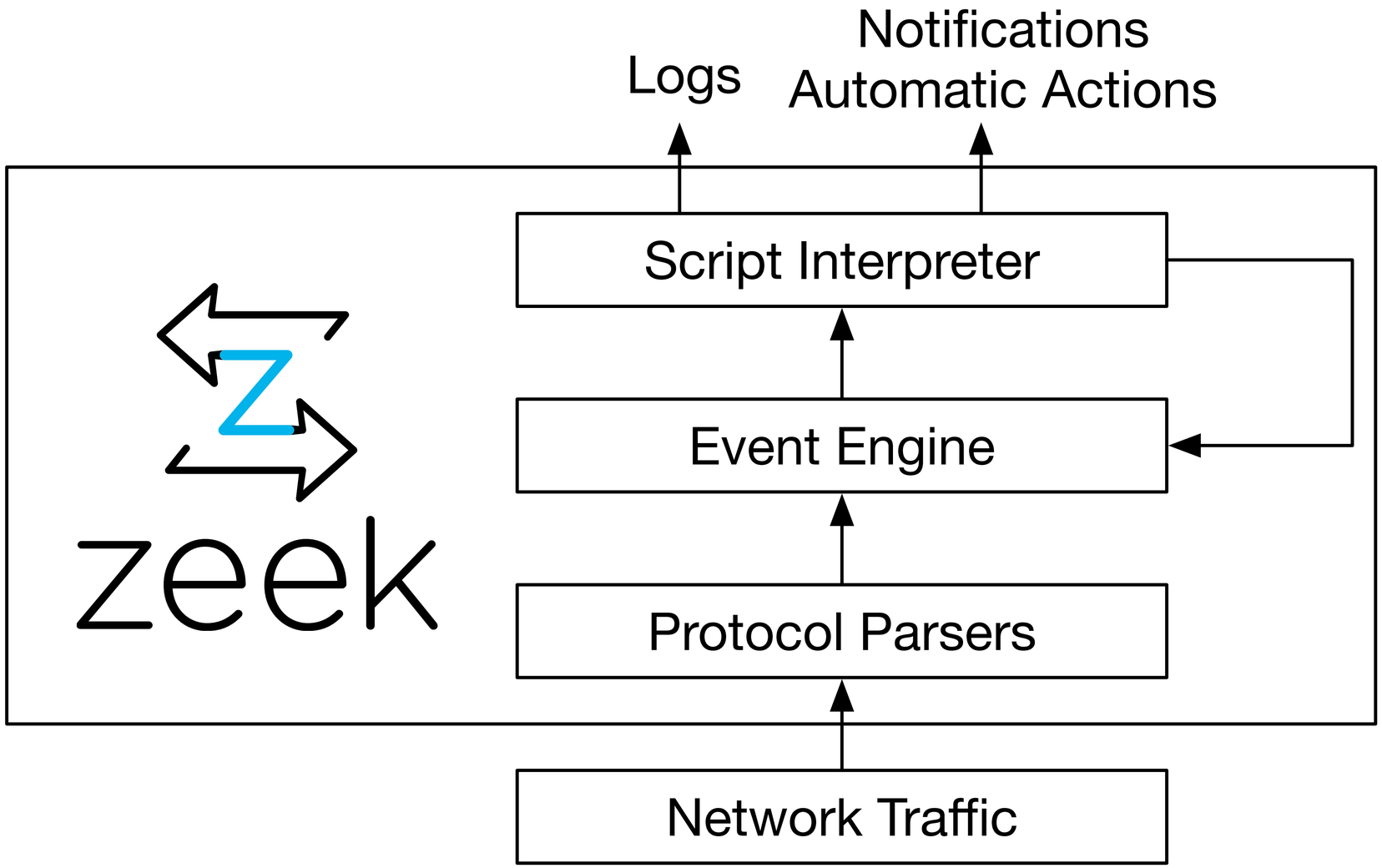

Incoming link packets
Outgoing link packets
Flow reorder device
50% traffic per link,
whole sessions
Monitoring machine


Incoming link packets
Outgoing link packets
Flow reorder device
50% traffic per link,
whole sessions
Monitoring machine

AF_PACKET Fanout



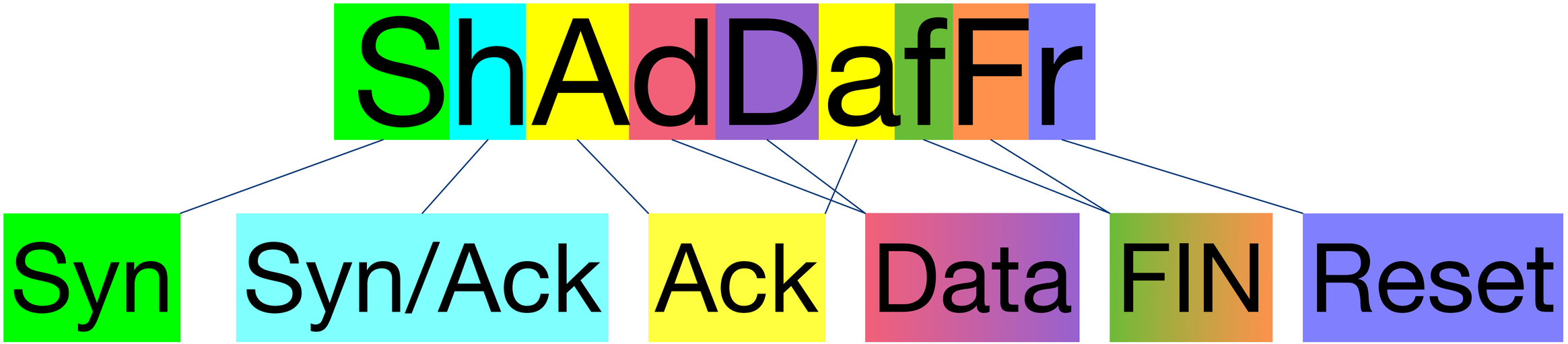
What is Zeek?


Logs
Notifications
Automatic Actions
Script Interpreter
Event Engine
Protocol Parsers
Network Traffic
zeek

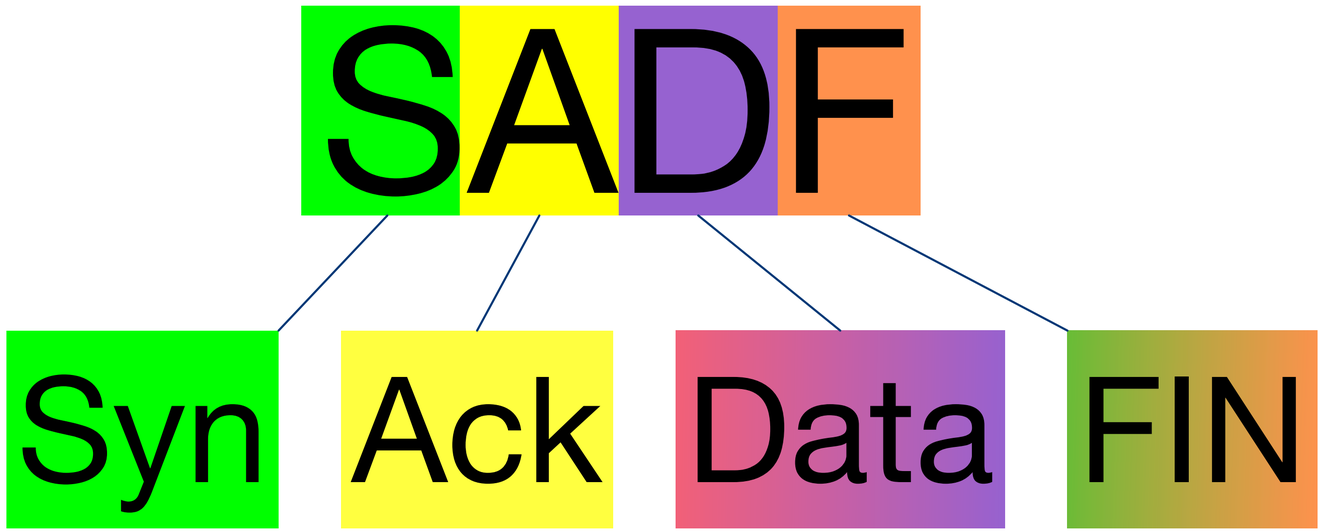
Check your data

- Goal: Be sure that your data is complete and internally consistent
- Often surprisingly tricky to do when you have a large amount of data
- First step: check that your TCP (and UDP) sessions look reasonable

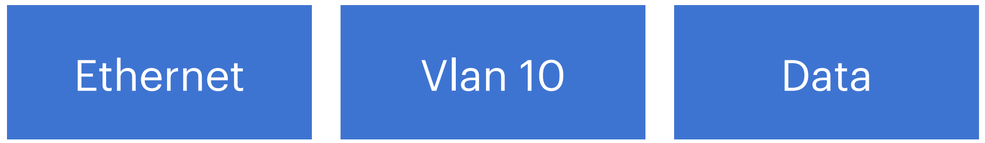
Zeek Connection History



Zeek Connection History

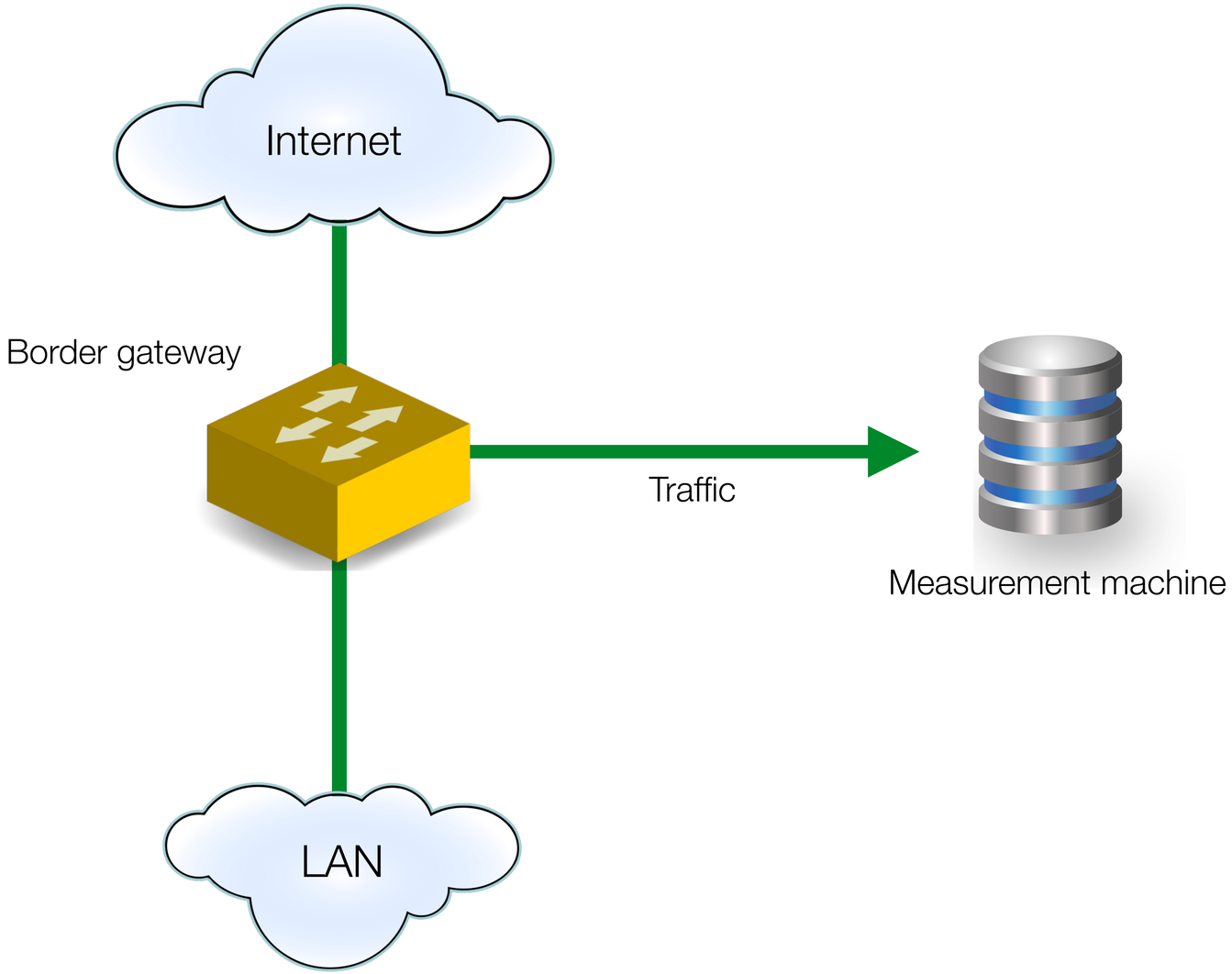


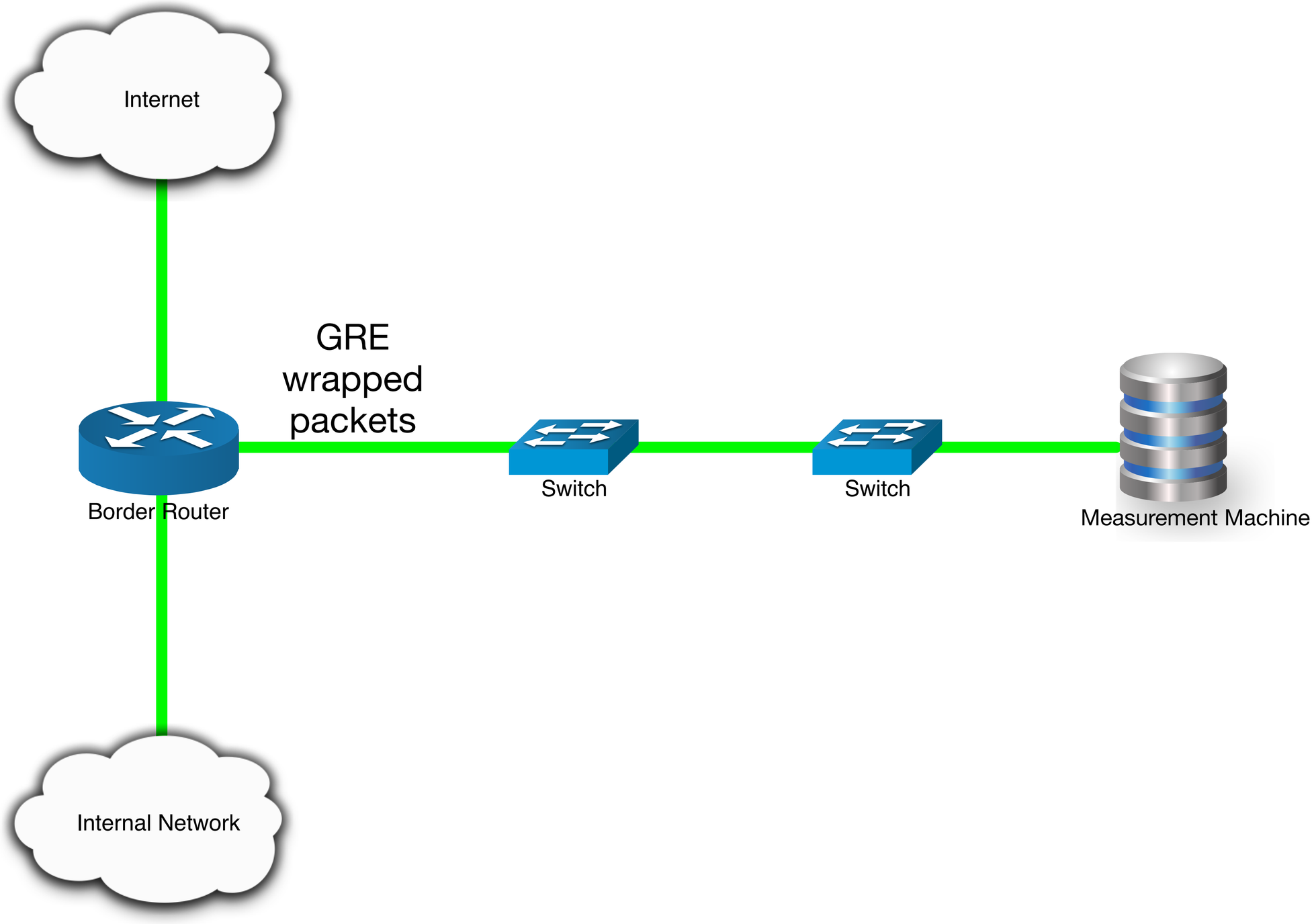
Check that your data is complete



Check that your data is complete

Typical Network Monitoring Setup

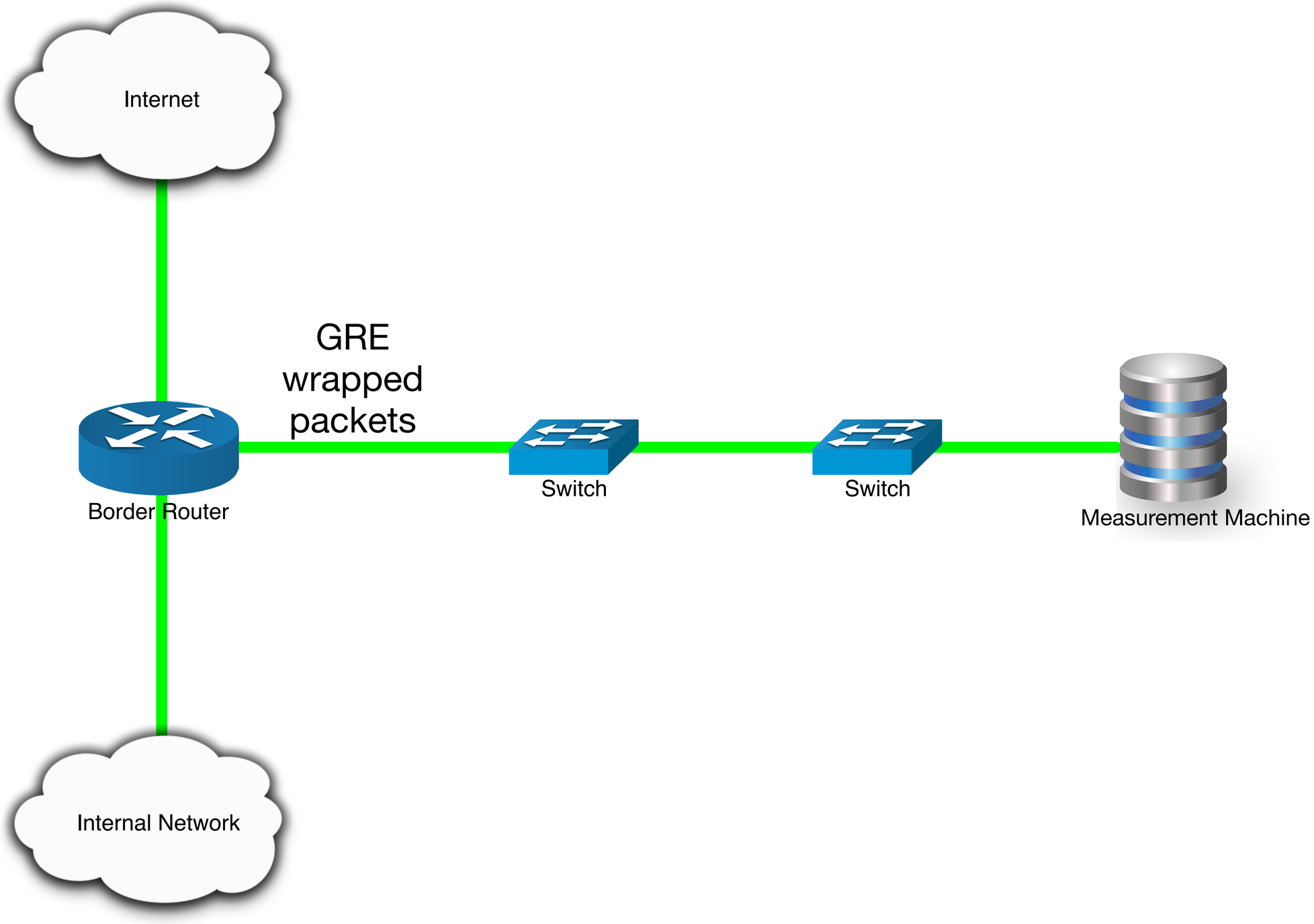



Internet
GRE
wrapped
packets
Border Router
Switch
Switch
Measurement Machine
Internal Network

Capture loss

- Zeek log that uses TCP Gap/ACK analysis to determine actual amount of data lost

ts_delta	Gaps	Acks	Perecent_lost
900	93372	4593277	2.04


Internet
GRE
wrapped
packets
Border Router
Switch
Switch
Measurement Machine
Internal Network


Check your data - and your pipeline

How do you get contributors?

Getting contributors

- Asking gets you surprisingly far
- Operations often are interesting in helping you
- It pays off to have good long-term relationships
- People that do this operationally already have monitoring, hardware, etc
  So you get the data without having to spend your research money on it
- But - you don’t control the data pipeline - so you can’t guarantee its accuracy or bias
- Software updates are hard
- Think about schemas early
  Make them extensible
  You probably still will end up with a mess :)

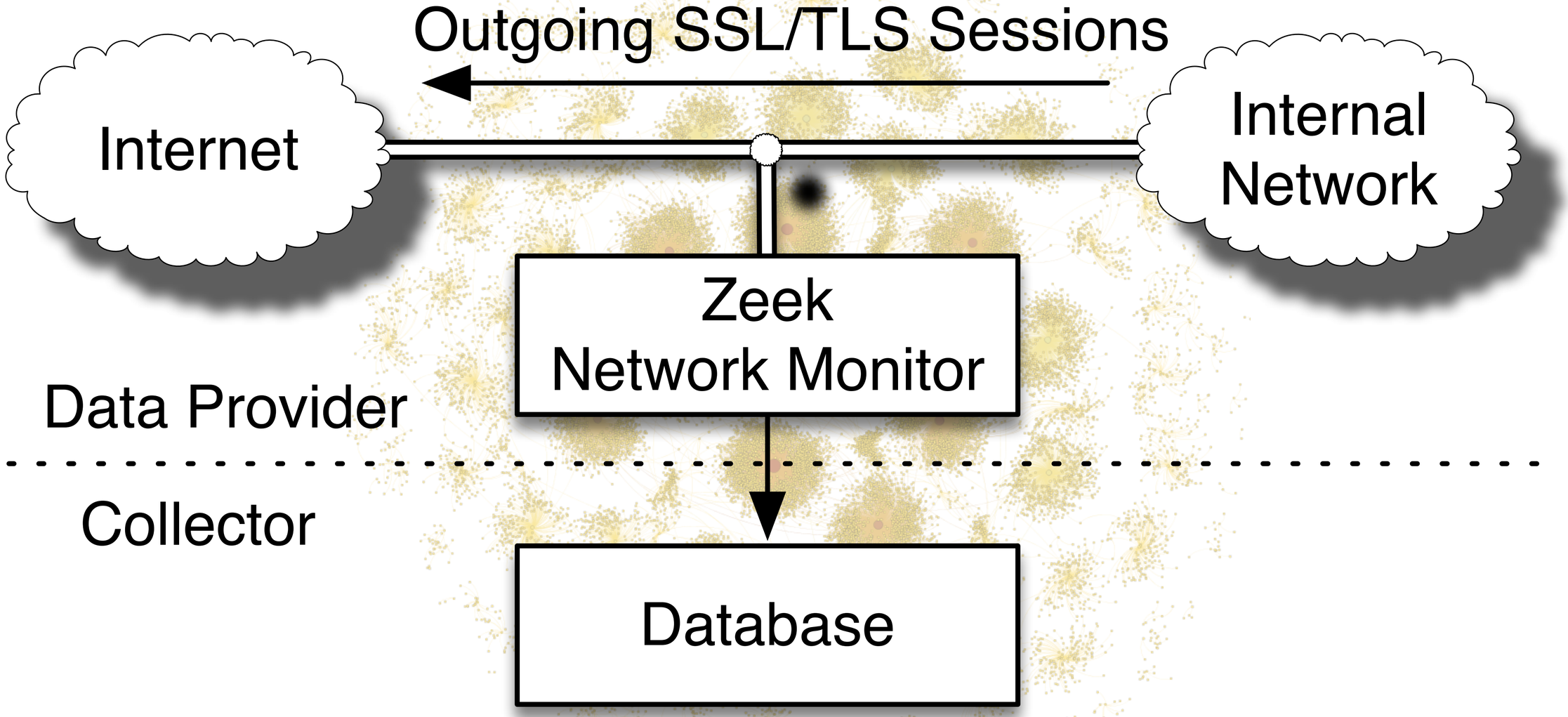
Lessons so far

- Setting passive measurements up correctly takes time
- Think about ethics early
- Validate your measurements - and continue re-checking them.
  Things can (and will) break.
- Debugging these issues can take a lot of time
  It is not always possible to fix things easily, even when you identified the issue
- External contributors are great - but you don’t control the pipeline

Part 2

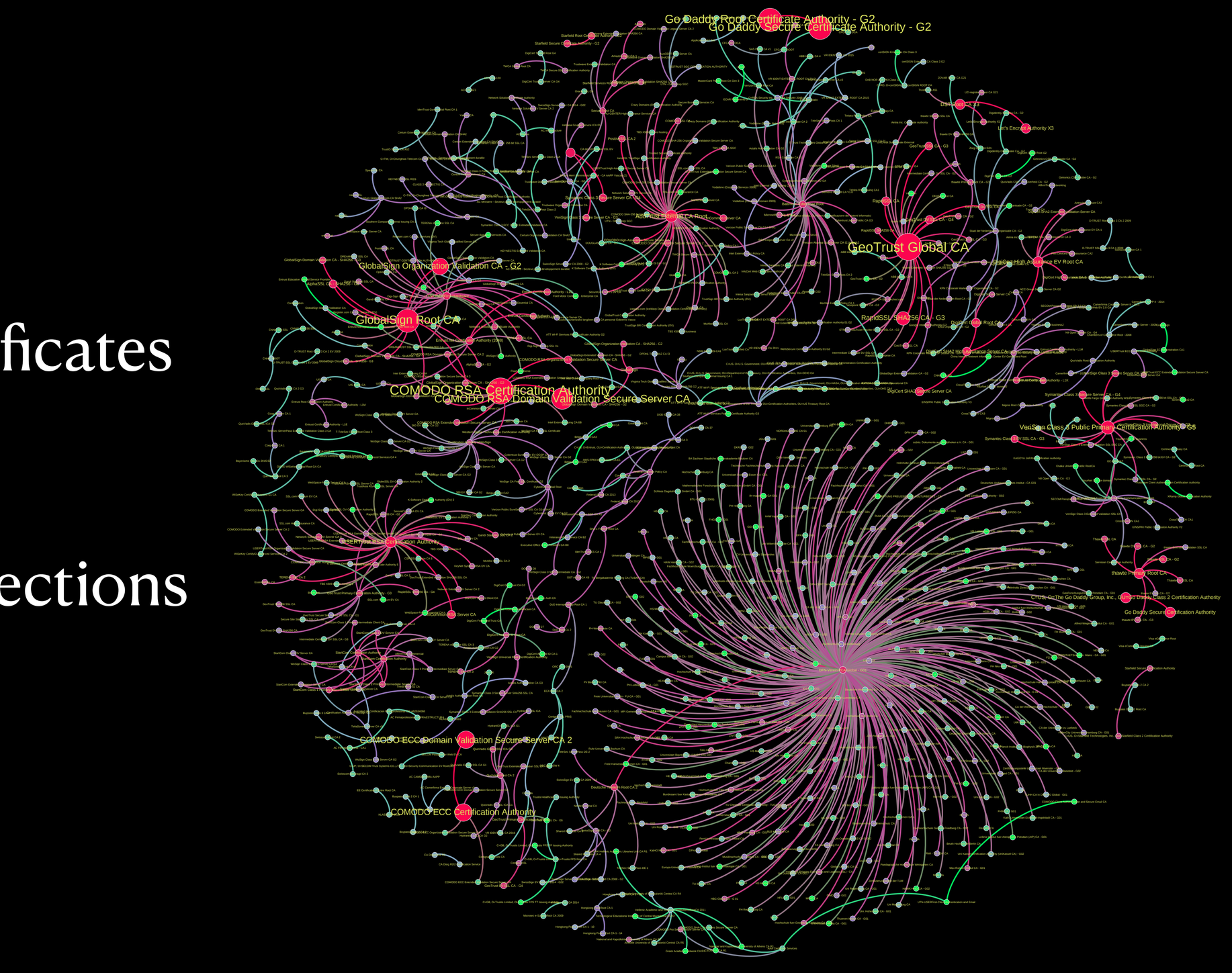
TLS and Protocol Weirdnesses

ICSI Notary

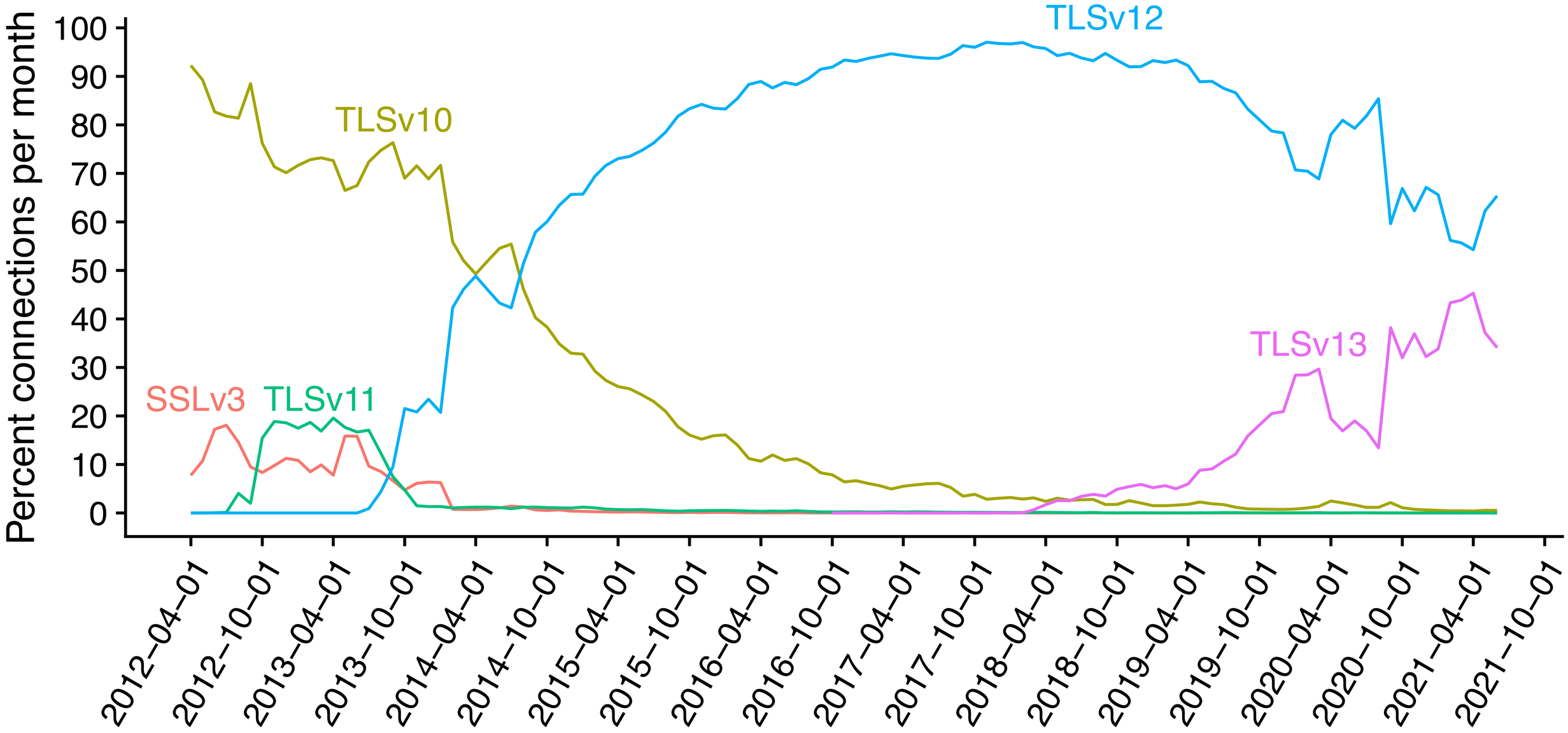

Outgoing SSL/TLS Sessions
Internet
Internal Network
Zeek Network Monitor
Data Provider
Collector
Database

236 Million certificates

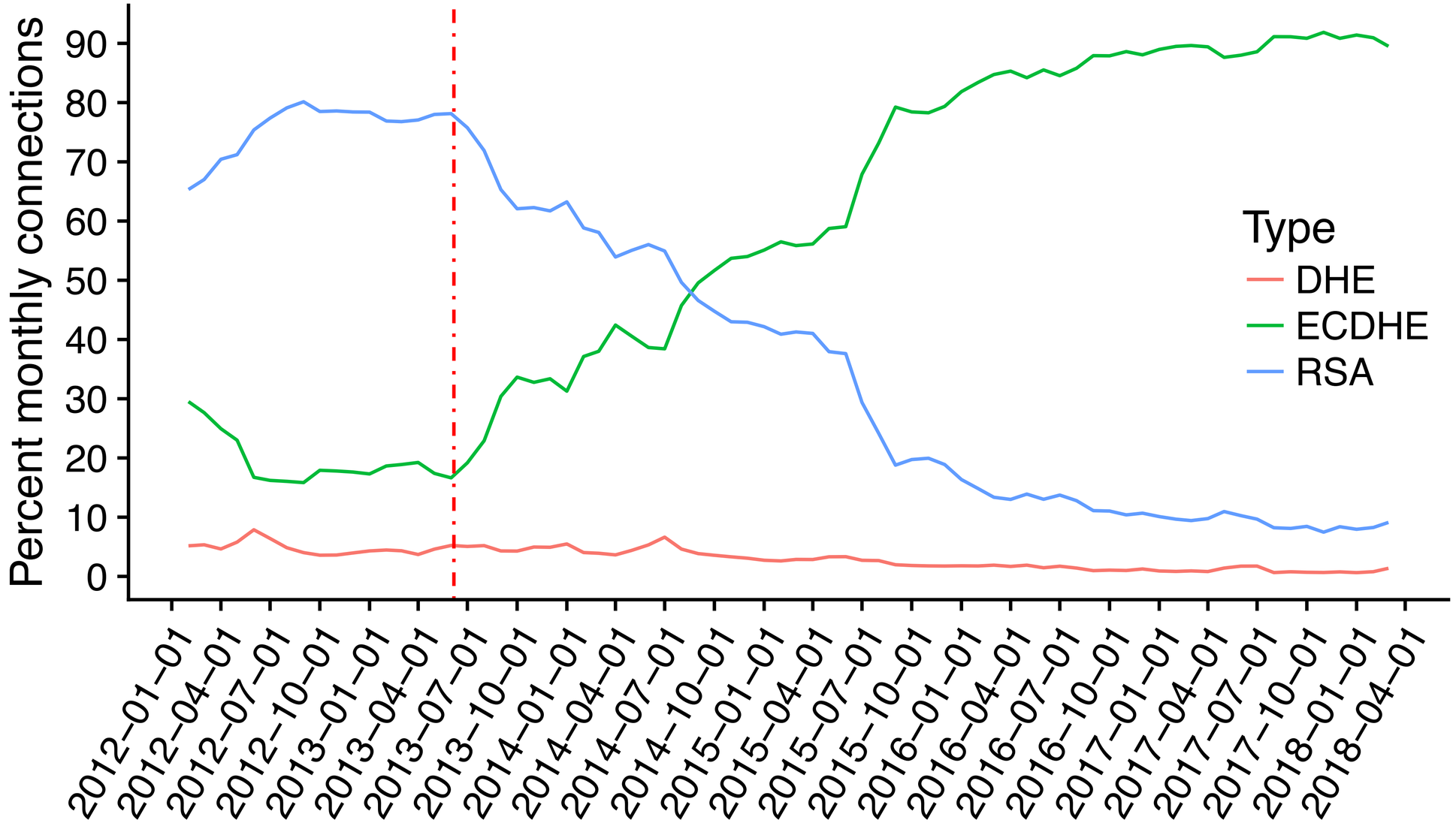
443 Billion connections



TLS Versions



Negotiated RSA vs forward secret



Coming of Age: A Longitudinal Study of TLS Deployment
P. Kotzias, A. Razaghpanah, J. Amann, K. Paterson, N. Vallina-Rodriguez, J. Caballero, IMC 2018

What is a certificate?

Version	3 (0x2)
Serial	0b:52:36:05:c5:be:20…
Signature Algorithm	sha256WithRSAEncryption
Issuer	C = US, O = Google Trust Services LLC, […]
Valid NotBefore	Feb 28 02:21:45 2022 GMT
Valid NotAfter	May 23 02:21:44 2022 GMT
Subject	CN = *.google.com
SPKI (Key Information)	[…]
Extensions	[…]

What's weird about this one?

Version	3 (0x2)
Serial	0b:52:36:05:[..]
Signature Algorithm	sha256WithRSAEncryption
Issuer	CN=idrac-[…], O=Dell Inc.
Valid NotBefore	Feb 28 14:52:00 2016 GMT
Valid NotAfter	Feb 29 14:52:00 2026 GMT
Subject	CN=idrac-[…], O=Dell Inc.
SPKI (Key Information)	[…]
Extensions	[…]

What's weird about this one?

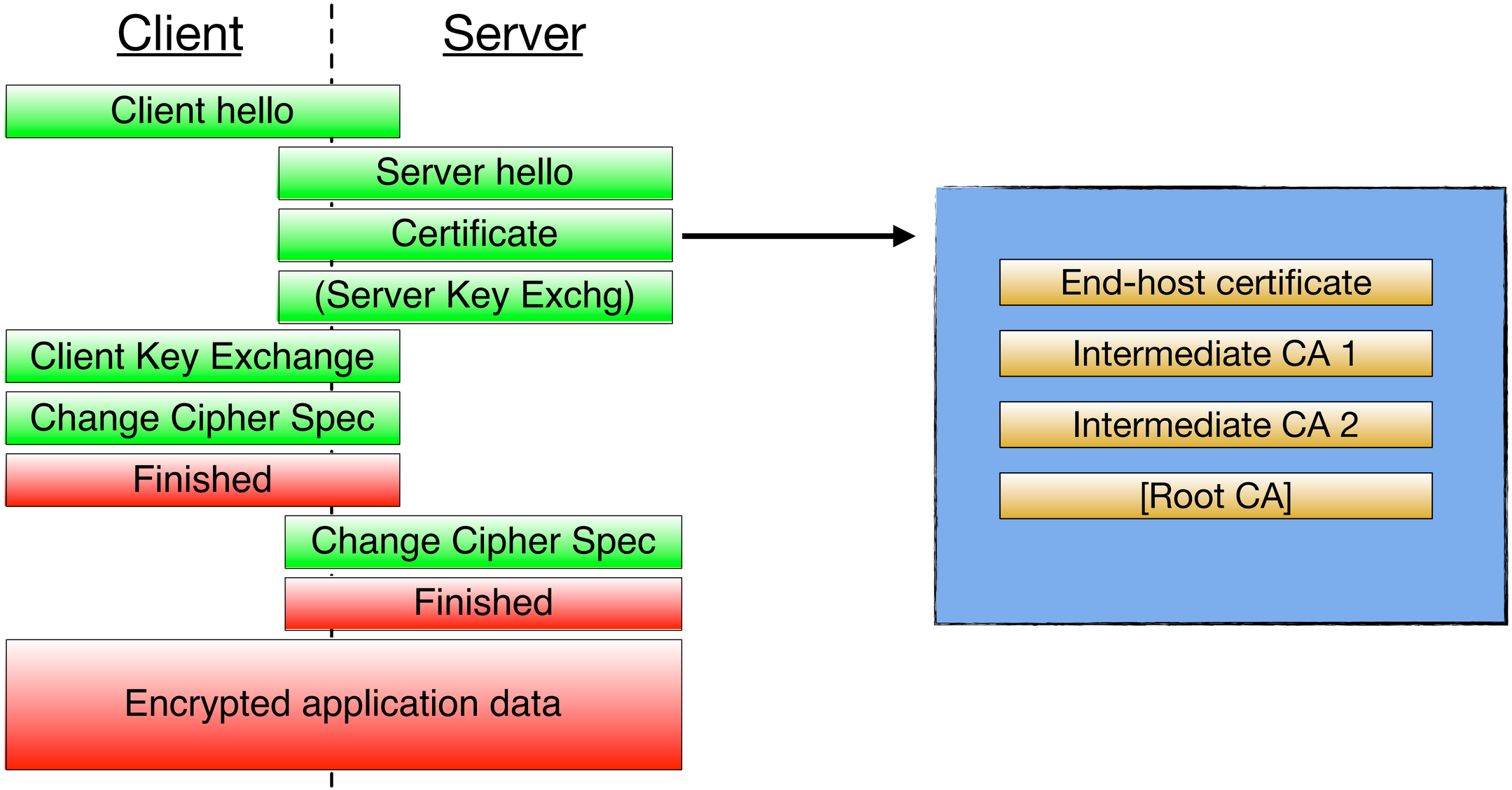
Version	3 (0x2)
Serial	0b:52:36:05:[..]
Signature Algorithm	sha256WithRSAEncryption
Issuer	CN=idrac-[…], O=Dell Inc.
Valid NotBefore	Feb 28 14:52:00 2016 GMT
Valid NotAfter	Feb 29 14:52:00 2026 GMT
Subject	CN=idrac-[…], O=Dell Inc.
SPKI (Key Information)	[…]
Extensions	[…]

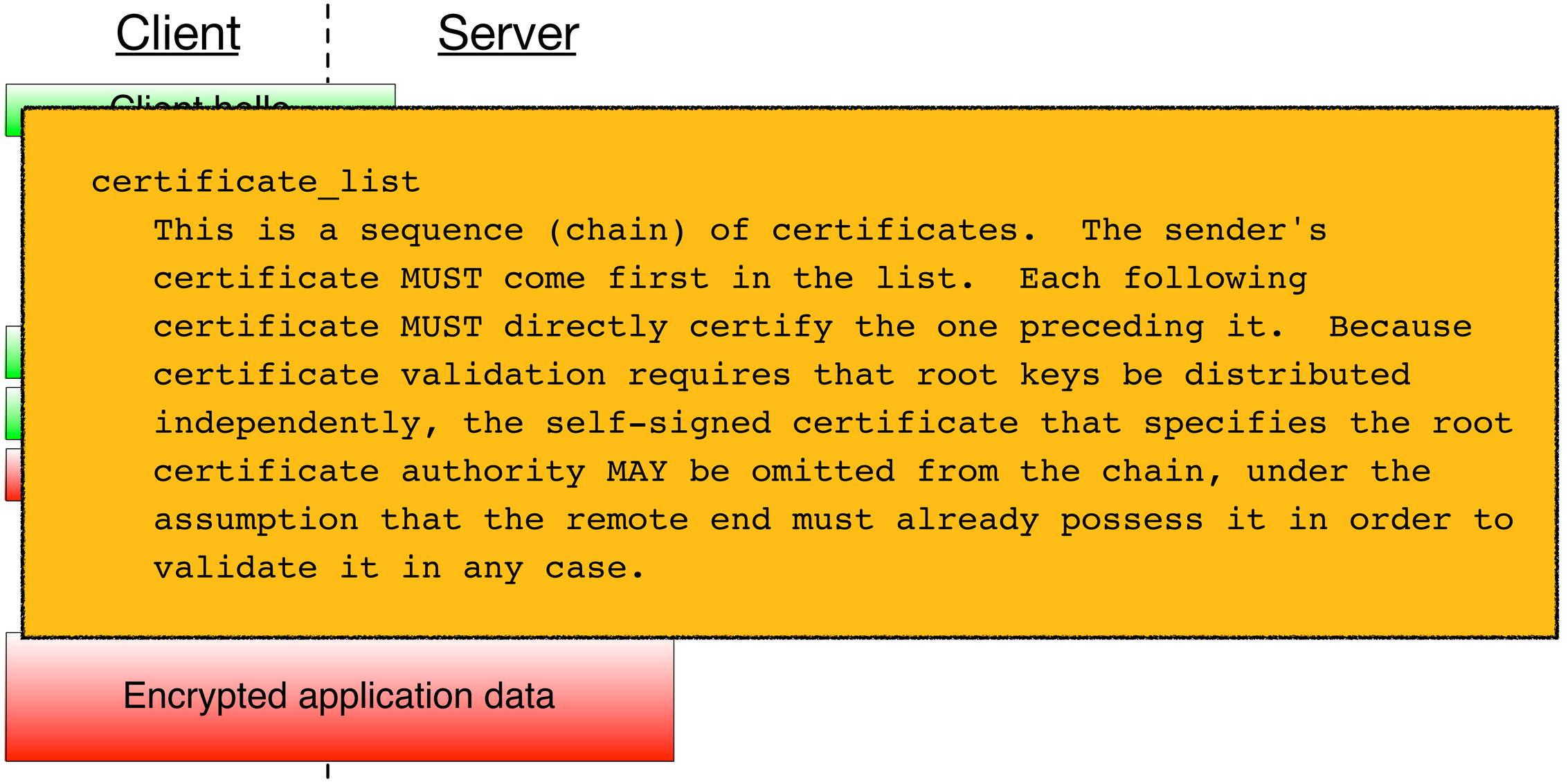
One last one

Version	4 (0x3)
Serial	32112[..]
Signature Algorithm	sha256WithRSAEncryption
Issuer	O = Acronis INC, […] CN = Datacenter CA
Valid NotBefore	Jul 4 06:55:07 2019 GMT
Valid NotAfter	Jul 3 06:55:07 2022 GMT
Subject	CN = Registration Server CA, […]
SPKI (Key Information)	[…]
Extensions	[…]

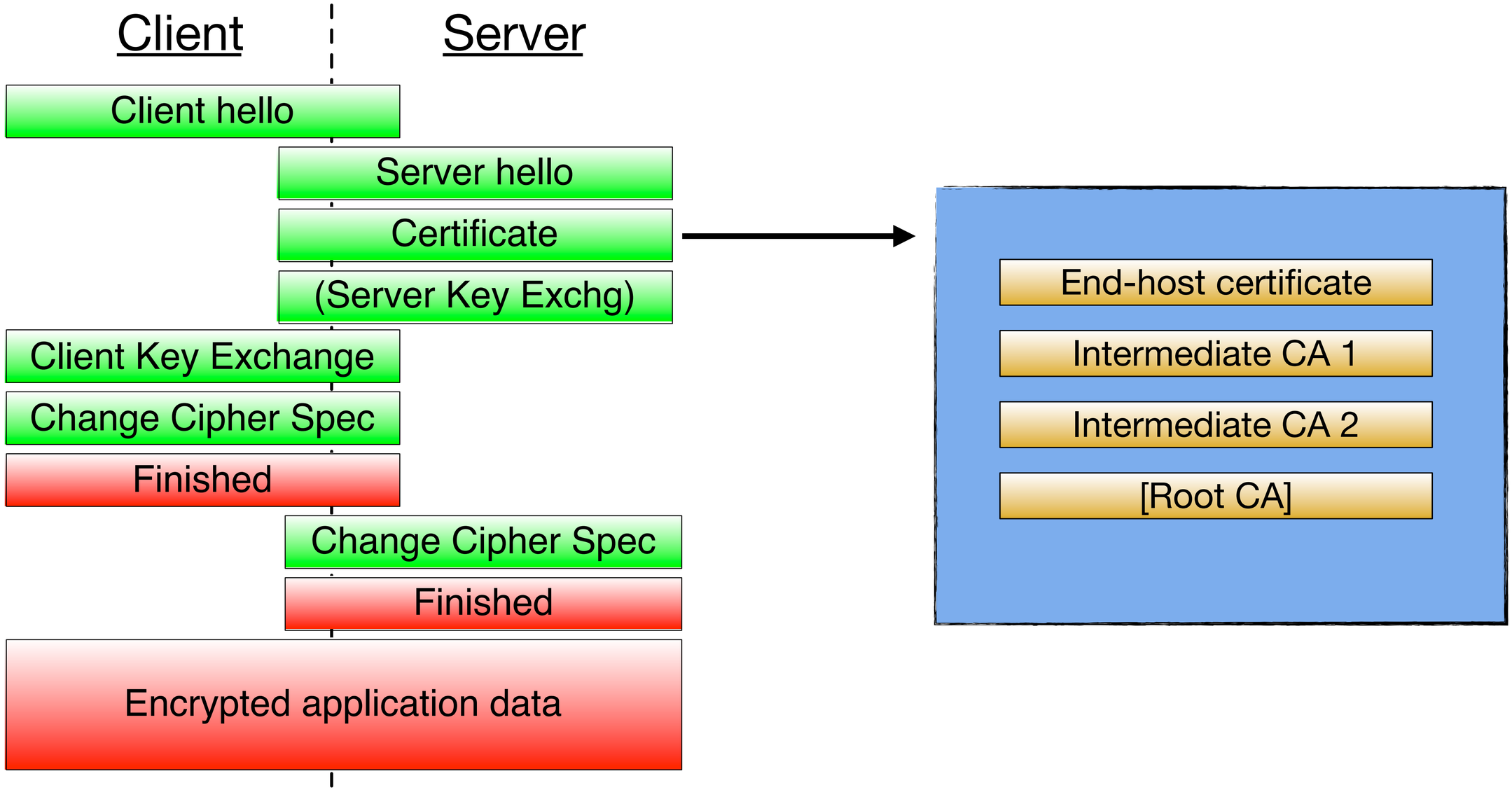
One last one

Version	4 (0x3)
Serial	32112[..]
Signature Algorithm	sha256WithRSAEncryption
Issuer	O = Acronis INC, […] CN = Datacenter CA
Valid NotBefore	Jul 4 06:55:07 2019 GMT
Valid NotAfter	Jul 3 06:55:07 2022 GMT
Subject	CN = Registration Server CA, […]
SPKI (Key Information)	[…]
Extensions	[…]


Client
Server
Client hello
Server hello
Certificate
(Server Key Exchg)
Client Key Exchange
Change Cipher Spec
Finished
Change Cipher Spec
Finished
Encrypted application data
End-host certificate
Intermediate CA 1
Intermediate CA 2
[Root CA]



certificate_list
This is a sequence (chain) of certificates. The sender's certificate MUST come first in the list. Each following certificate MUST directly certify the one preceding it. Because certificate validation requires that root keys be distributed independently, the self-signed certificate that specifies the root certificate authority MAY be omitted from the chain, under the assumption that the remote end must already possess it in order to validate it in any case.


Client
Server
Client hello
Server hello
Certificate
(Server Key Exchg)
Client Key Exchange
Change Cipher Spec
Finished
Change Cipher Spec
Finished
Encrypted application data
End-host certificate
Intermediate CA 1
Intermediate CA 2
[Root CA]

In Practice...

End-host certificate

No intermediates - common on Microsoft properties

End-host certificate

Old End-host certificate

Intermediates

Old certificates, or test certificates in the chain

Also - data after the certificate. Typically ignored during parsing.

```
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number:
            36:9a:c7:3d:67:06:3a:a2:75:83:0d:fc:66:84:1c:1e
    Signature Algorithm: sha256WithRSAEncryption
        Issuer: C=US, O=Symantec Corporation, OU=Symantec Trust Network, CN=Symantec Class 3 Secure Server CA - G4
        Validity
            Not Before: May 30 00:00:00 2016 GMT
            Not After : May 30 00:00:00 2018 GMT
        Subject: C=US, ST=Washington, L=Seattle, O=Amazon.com, Inc., CN=*.cloudfront.net
        X509v3 extensions:
            X509v3 Subject Alternative Name:
                DNS:cloudfront.net, DNS:*.cloudfront.net
            X509v3 Basic Constraints:
                CA:FALSE
            Authority Information Access:
                OCSP - URI:http://ss.symcd.com
                CA Issuers - URI:http://ss.symcb.com/ss.crt

            CT Precertificate SCTs:
                ..Random string goes here
```

```
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number:
            36:9a:c7:3d:67:06:3a:a2:75:83:0d:fc:66:84:1c:1e
    Signature Algorithm: sha256WithRSAEncryption
        Issuer: C=US, O=Symantec Corporation, OU=Symantec Trust Network, CN=Symantec Class 3 Secure Server CA - G4
        Validity
            Not Before: May 30 00:00:00 2016 GMT
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        Subject: C=US, ST=Washington, L=Seattle, O=Amazon.com, Inc., CN=*.cloudfront.net
        X509v3 extensions:
            X509v3 Subject Alternative Name:
                DNS:cloudfront.net, DNS:*.cloudfront.net
            X509v3 Basic Constraints:
                CA:FALSE
            Authority Information Access:
                OCSP - URI:http://ss.symcd.com
                CA Issuers - URI:http://ss.symcb.com/ss.crt

            CT Precertificate SCTs:
                ..Random string goes here
```

```
 853:d=5  hl=2 l=   3 prim: OBJECT            :X509v3 CRL Distribution Points
 858:d=5  hl=2 l=  36 prim: OCTET STRING      [HEX DUMP]:30223020A01EA01C861A687474703A2F2F73732E73796D63622E636F6D2F73732E63726C
 896:d=4  hl=2 l=  87 cons: SEQUENCE
 898:d=5  hl=2 l=   8 prim: OBJECT            :Authority Information Access
 908:d=5  hl=2 l=  75 prim: OCTET STRING      [HEX DUMP]:3049301F06082B06010505073001861368747470 3A2F2F73732E73796D63642E636F6D30260
D63622E636F6D2F73732E637274
 985:d=4  hl=2 l=  39 cons: SEQUENCE
 987:d=5  hl=2 l=  10 prim: OBJECT            :CT Precertificate SCTs
 999:d=5  hl=2 l=  25 prim: OCTET STRING      [HEX DUMP]:0C1752616E646F6D20737472696E6720676F65732068657265
```

```
 853:d=5  hl=2 l=   3 prim: OBJECT            :X509v3 CRL Distribution Points
 858:d=5  hl=2 l=  36 prim: OCTET STRING      [HEX DUMP]:30223020A01EA01C861A687474703A2F2F73732E73796D63622E636F6D2F73732E63726C
 896:d=4  hl=2 l=  87 cons: SEQUENCE
 898:d=5  hl=2 l=   8 prim: OBJECT            :Authority Information Access
 908:d=5  hl=2 l=  75 prim: OCTET STRING      [HEX DUMP]:3049301F06082B06010505073001861368747470 3A2F2F73732E73796D63642E636F6D30260
D63622E636F6D2F73732E637274
 985:d=4  hl=2 l=  39 cons: SEQUENCE
 987:d=5  hl=2 l=  10 prim: OBJECT            :CT Precertificate SCTs
 999:d=5  hl=2 l=  25 prim: OCTET STRING      [HEX DUMP]:0C1752616E646F6D20737472696E6720676F65732068657265
```

```
$ openssl asn1parse -in invalidsct.crt -inform der -strparse 999
    0:d=0  hl=2 l=  23 prim: UTF8STRING        :Random string goes here
```

Normal SCT

```
CT Precertificate SCTs:
    Signed Certificate Timestamp:
        Version   : v1(0)
        Log ID    : DD:EB:1D:2B:7A:0D:4F:A6:20:8B:81:AD:81:68:70:7E:
                    2E:8E:9D:01:D5:5C:88:8D:3D:11:C4:CD:B6:EC:BE:CC
        Timestamp : Aug 17 17:25:11.747 2016 GMT
        Extensions: none
        Signature : ecdsa-with-SHA256
                    30:46:02:21:00:B9:6C:2B:9A:D5:C8:70:EC:CD:2E:17:
                    E6:69:5E:C0:51:47:24:D5:DE:37:CF:10:54:84:A7:D6:
                    FD:6B:A4:A6:31:02:21:00:ED:0C:E0:49:63:60:D7:26:
                    DD:DD:06:B4:80:D6:42:FC:F4:C5:74:70:C5:4F:4D:8D:
                    9F:41:61:91:BB:B1:73:86
    Signed Certificate Timestamp:
        Version   : v1(0)
        Log ID    : A4:B9:09:90:B4:18:58:14:87:BB:13:A2:CC:67:70:0A:
                    3C:35:98:04:F9:1B:DF:B8:E3:77:CD:0E:C8:0D:DC:10
        Timestamp : Aug 17 17:25:11.810 2016 GMT
        Extensions: none
        Signature : ecdsa-with-SHA256
                    30:45:02:21:00:C4:A9:7D:4B:93:C1:57:BB:AF:39:01:
                    D9:5B:CB:01:35:44:97:7A:9B:E9:FD:A2:F7:15:CA:F2:
                    16:4B:88:5E:AC:02:20:10:9D:1E:54:8D:3A:C1:20:65:
                    A9:25:BE:8F:00:8E:26:26:2D:D8:E7:BA:AE:48:84:19:
                    35:86:0D:B8:EC:B3:D4
```

```
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number:
            36:9a:c7:3d:67:06:3a:a2:75:83:0d:fc:66:84:1c:1e
    Signature Algorithm: sha256WithRSAEncryption
        Issuer: C=US, O=Symantec Corporation, OU=Symantec Trust Network, CN=Symantec Class 3 Secure Server CA - G4
        Validity
            Not Before: May 30 00:00:00 2016 GMT
            Not After : May 30 00:00:00 2018 GMT
        Subject: C=US, ST=Washington, L=Seattle, O=Amazon.com, Inc., CN=*.cloudfront.net
        X509v3 extensions:
            X509v3 Subject Alternative Name:
                DNS:cloudfront.net, DNS:*.cloudfront.net
            X509v3 Basic Constraints:
                CA:FALSE
            Authority Information Access:
                OCSP - URI:http://ss.symcd.com
                CA Issuers - URI:http://ss.symcb.com/ss.crt

            CT Precertificate SCTs:
                ..Random string goes here
```

A small list of things we have seen:

- Invalid hostnames
- Invalid certificate versions...
- Extra certificates
- Unordered certificates
- Missing certificates
- Extra bytes after certificates
- Data that is not certificates
- Autogenerated certificates
- Certificates with unusual choices in algorithms
- Fake certificates

Takeaways

- Check how your measurement infrastructure deals with outliers/edge behavior
- There will be something that you did not think of
- If something seems weird - dig into it.
  It is fun - and there is a chance that you will find something interesting.
- When writing papers, figuring out all the edge-cases takes quite a while.
  This stings, especially when you are rejected - lots of repeated work

Consider capturing your traffic...

...even when you perform active measurements

- You get repeatability
- You can go back to the raw data and check for things you might have missed...
  - Unimplemented protocol features
  - Responses that you recorded wrong
- This works even for encrypted traffic - you can save your key material!

Thank you

This work would not have been possible without the work of a lot of other people. Thank you very much to Robin Sommer, Christian Kreibich, Seth Hall, Matthias Vallentin, Aashish Sharma, Vern Paxson, Ralph Holz, Jens Hiller, Platon Kotzias, Kenny Paterson - and many others that worked on this over the years.

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And finally - thank you to the photographers of Unsplash.