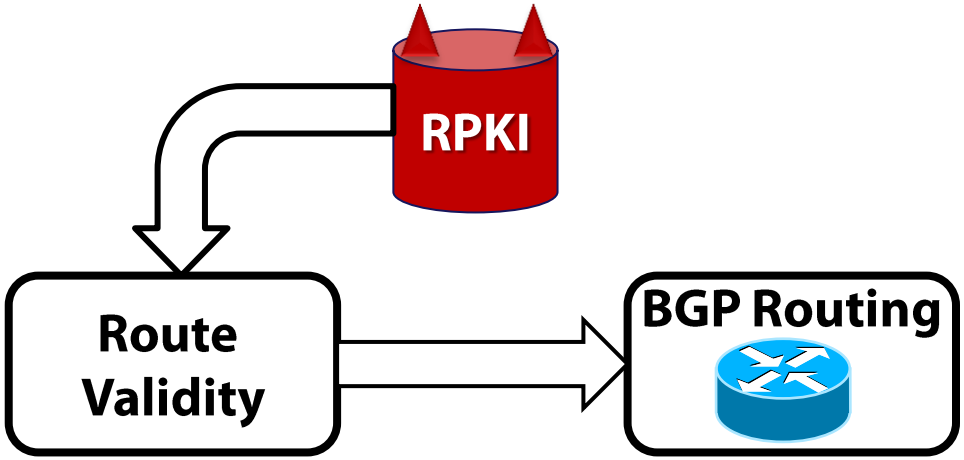
On the Risk of Misbehaving RPKI Authorities

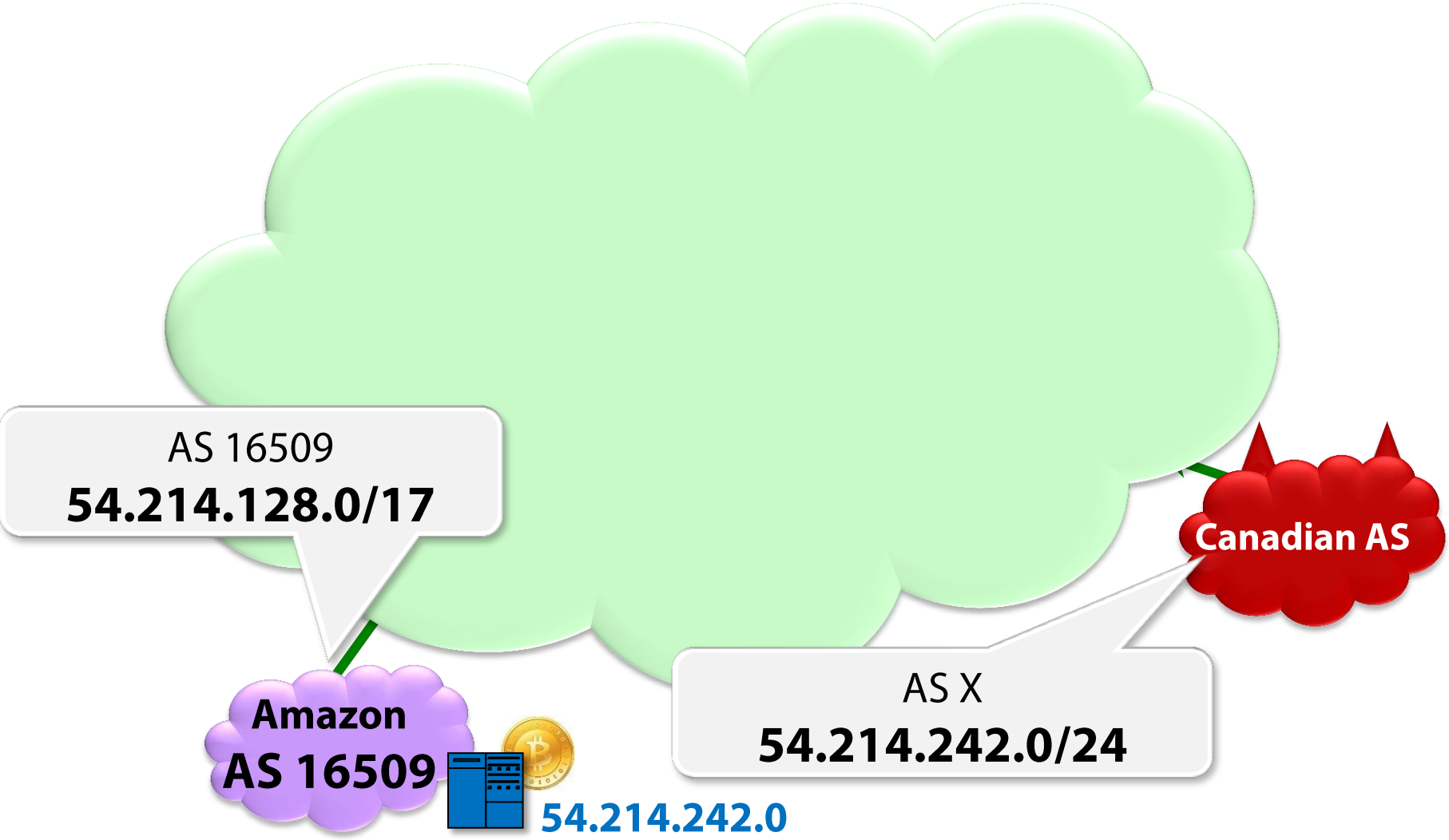


BOSTON UNIVERSITY

Sharon Goldberg

Danny Cooper, Ethan Heilman, Kyle Brogle, Leonid Reyzin

the canadian bitcoin BGP subprefix hijack (feb 3, 2014)



Sources: http://www.bgpmon.net/the-canadian-bitcoin-hijack/
http://www.secureworks.com/cyber-threat-intelligence/threats/bgp-hijacking-for-cryptocurrency-profit/

and many other BGP prefix hijacks…

2010
REPORT TO CONGRESS
of the
U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

Interception of Internet Traffic

For a brief period in April 2010, a state-owned Chinese telecommunications firm "hijacked" massive volumes of Internet traffic.* [114] Evidence related to this incident does not clearly indicate whether it was perpetrated intentionally and, if so, to what ends. However, computer security researchers have noted that the capability could enable severe malicious activities.[115]

The New York Times
The Lede
The New York Times News Blog

Pakistan Blamed for Worldwide YouTube Break

By MIKE NIZZA FEBRUARY 25, 2008 9:34 AM

If all had gone according to plan, Pakistan would have be
latest government taking part in an unsettling trend from
edecessors, tho
beyond its bor
y you couldn't

renesys

Con-Ed Steals the 'Net

22 JAN, 2006 | 11:06 PM | BY TODD UNDERWOOD

Well, not the whole Internet, but Con Edison (AS27506)
the Internet earlier today, probably by mistake. Earlier th
NANOG mailing list claiming that Con Ed was "stealing"

NetClean
WhiteBox

WIRED GEAR SCIENCE ENTERTAINMENT BUSINESS SECURITY DESIGN OPINION M

Someone's Been Siphoning Data Through a Huge Security Hole in the Internet

BY KIM ZETTER 12.05.13 | 6:30 AM | PERMALINK

Traceroute Path 2: from Denver, CO to Denver, CO via *Iceland*

Hijacked traffic went all the way to Iceland, where it may have been copied before being released to its intended destination. The green arrows show the path the traffic should have traveled; the red arrows show the path it took. *Map courtesy of Renesys*

BGPMON

Hijack event today by Indosat

Posted by Andree Toonk - April 3, 2014 - Hijack, News and Updates - 1 Comment

Today we observed a large-scale 'hijack' event that affected many of the prefixes on the Internet.

Symantec. Confidence in a connected world. United States

Spam and Fraud Activity Trends

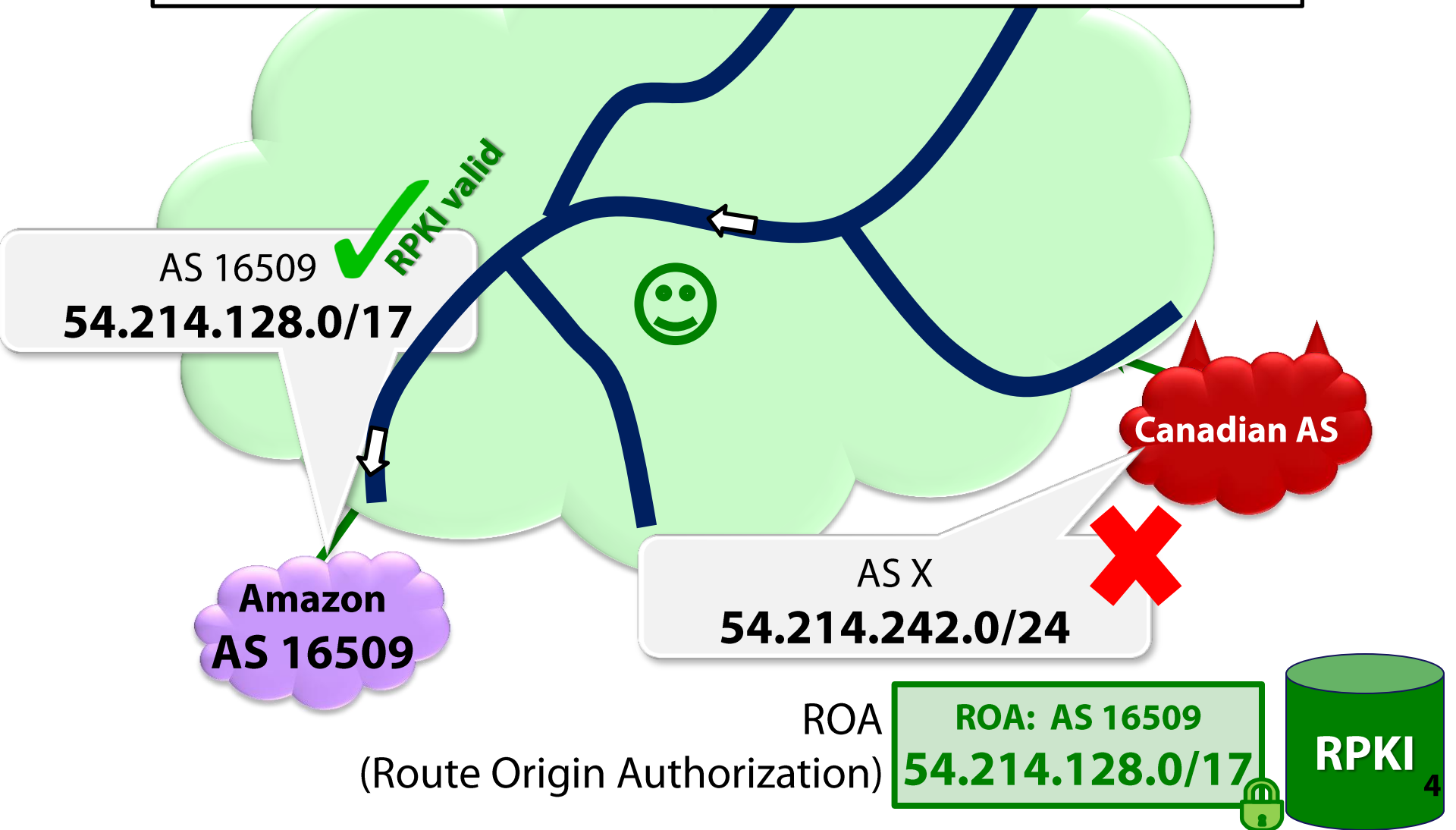
Future Spam Trends: BGP Hijacking
Case Study - Beware of "Fly-by Spammers"

Background

what is the fundamental vulnerability?

Problem: Route origin announcements are not authenticated.

Solution: The RPKI authenticates route origins.



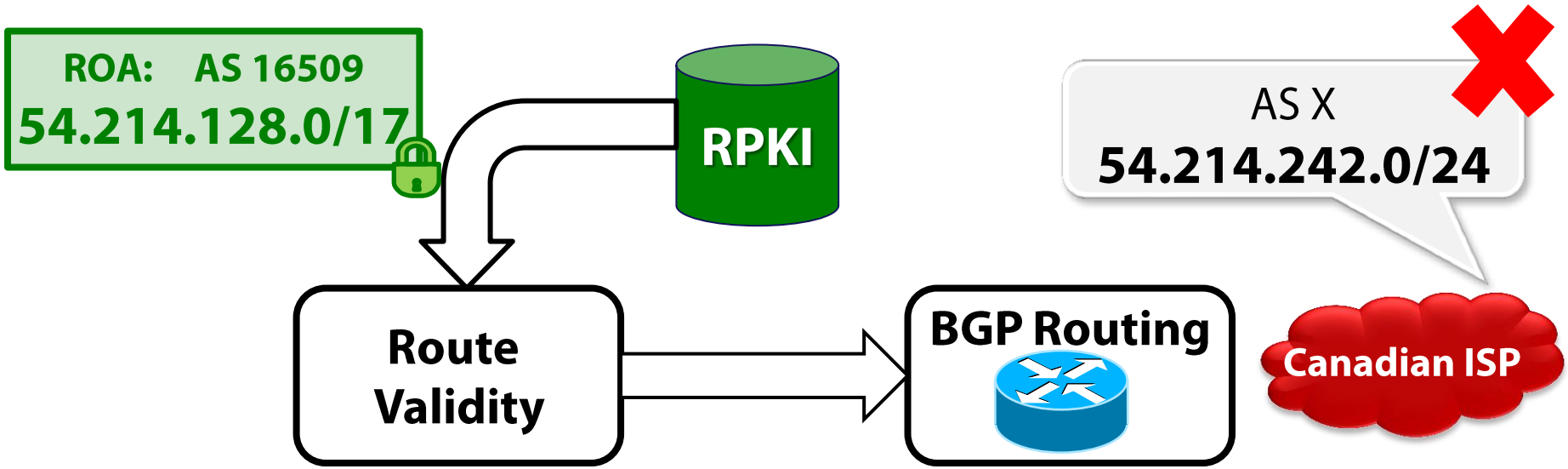
the Resource Public Key Infrastructure (RPKI) [RFC6480]

- **How does the RPKI protect routing?**
  - It prevents prefix & subprefix hijacks caused by common misconfigs
  - Advanced path-validation solutions build on RPKI
    - BGPSEC **[L'12]** Secure BGP **[KLS'99]**, soBGP **[W'03]**,…
  - Even without path validation, our research **[SIGCOMM'10, SIGCOMM'13]** shows RPKI is good at limiting advanced BGP attacks

- **What about other routing security solutions?**
  - Anomaly detectors alarm when strange routes appear
    - BGPmon, renesys, pgBGP **[KFR'06]**, PHAS **[LMPWZZ'06]**, …
  - Prefix filtering with IRRs
    - Requires distant ASes to implement filtering properly
    - Usually performed only on customer edges

traditional threat model for the RPKI

The RPKI is trusted but routing is under attack.

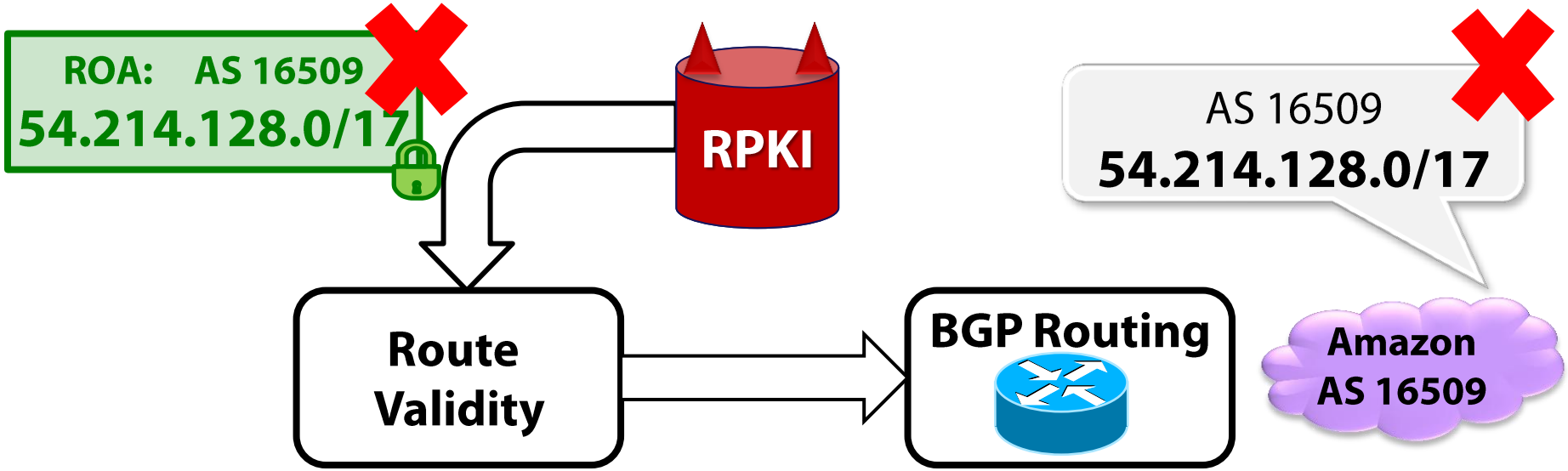


talk outline

Security audit of the RPKI [HotNets'13]

Misbehaving RPKI authorities can blackhole routes in BGP. Why?

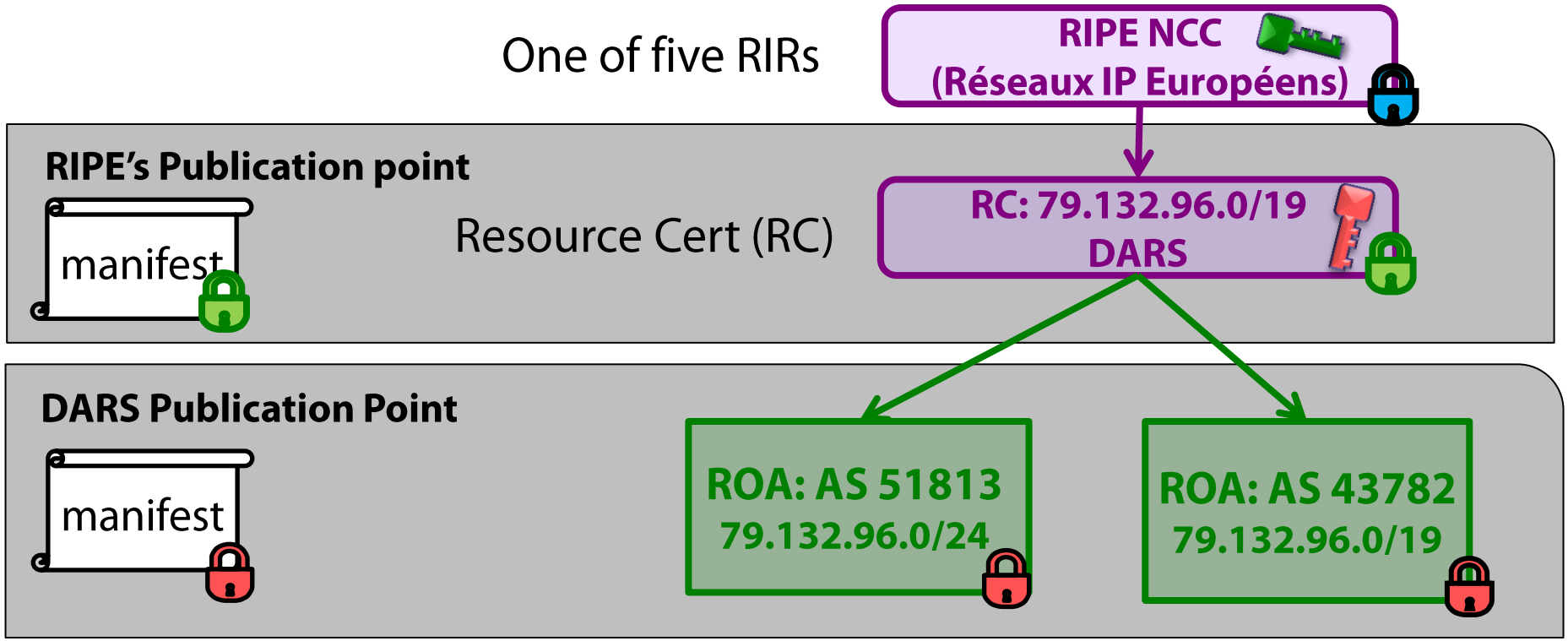
1. RPKI authorities can whack ROAs
2. Whacked ROAs can cause BGP routes to become **invalid**
3. Should drop **invalid** BGP routes to stop **sub**prefix hijacks.



Proposal to require consent to whack objects [SIGCOMM'14]

- There is a draft for similar proposal: **[draft-kent-sidr-suspenders-02]**

structure of the RPKI [RFC 6480]

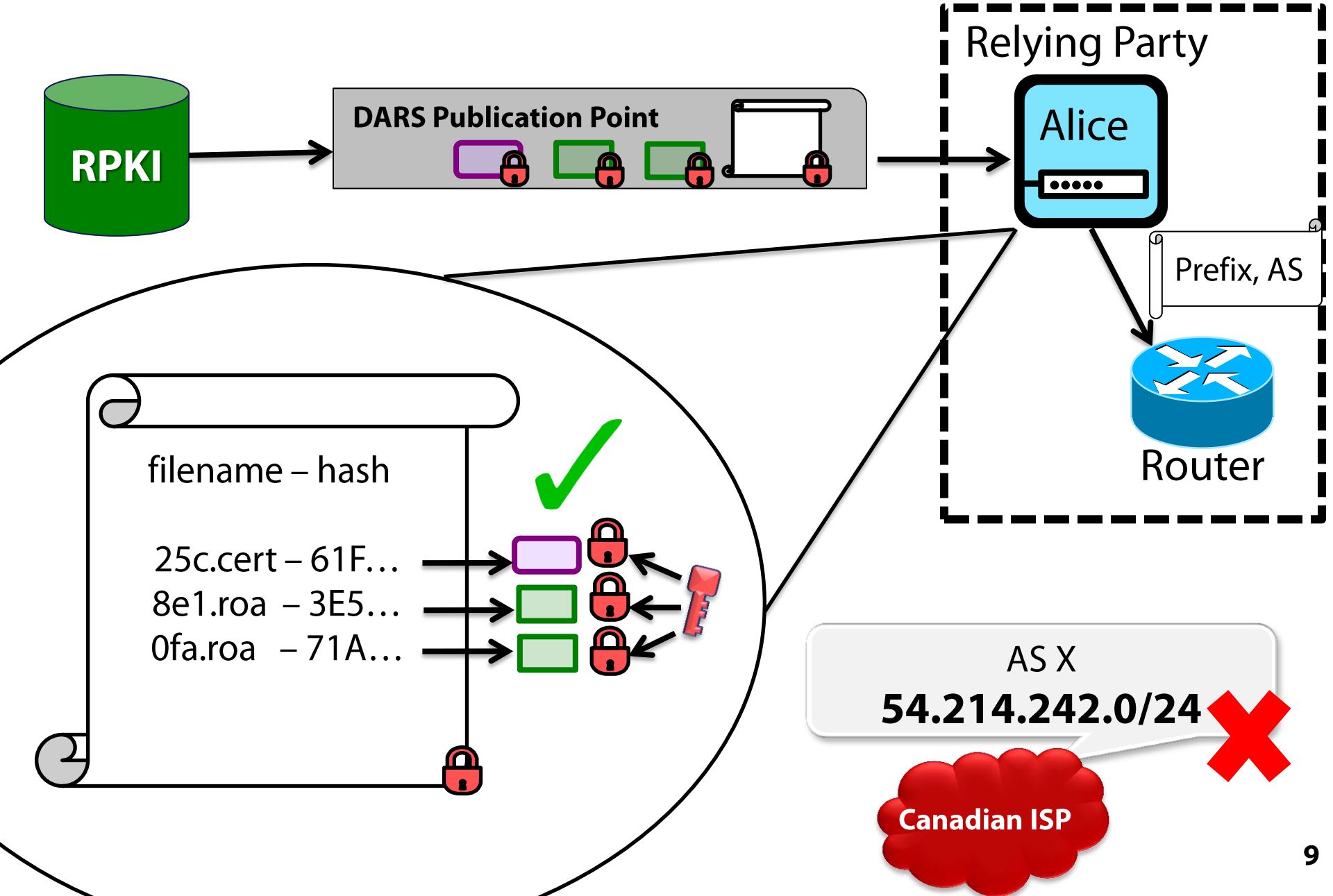


(ROA) Route Origin Authorization

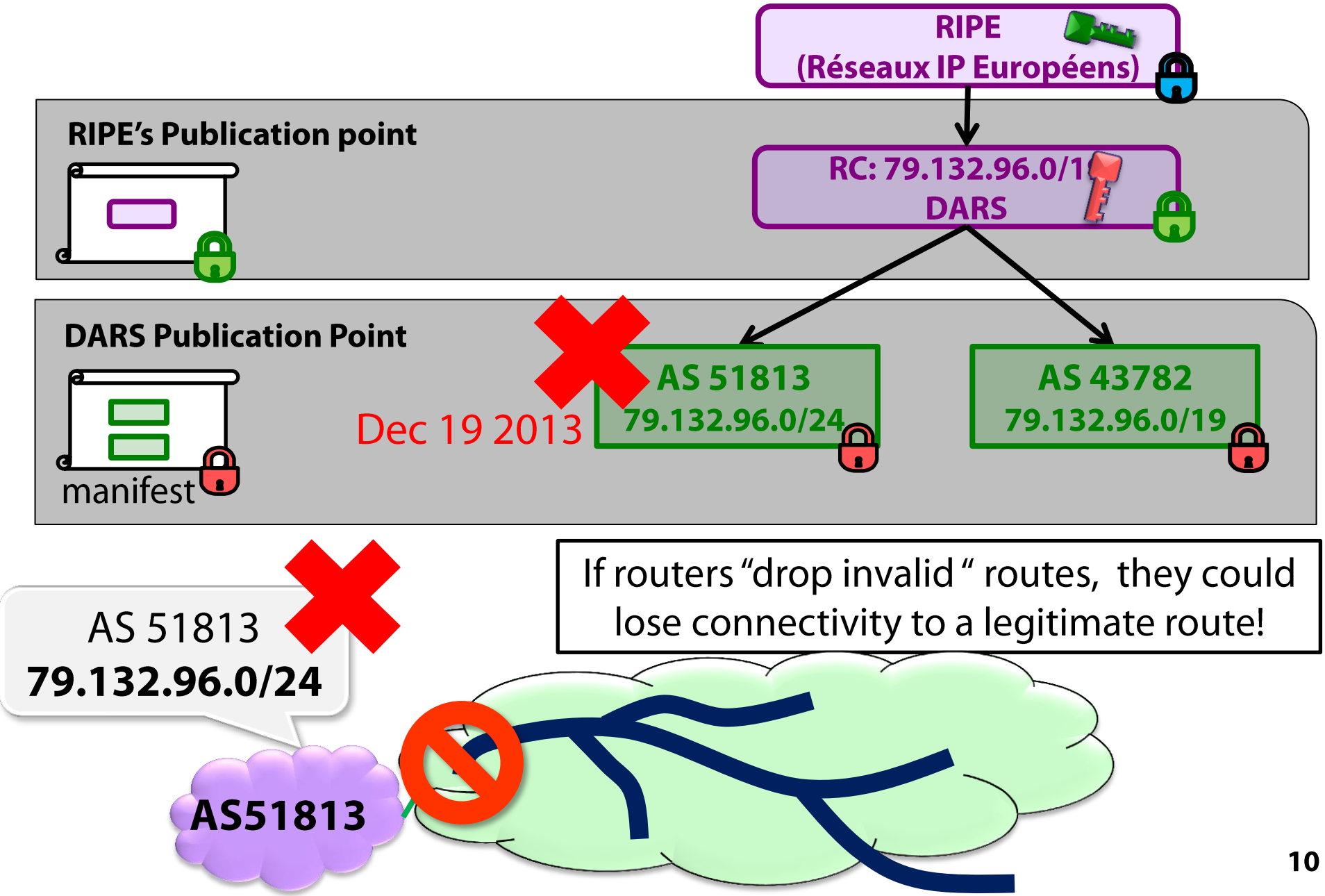
Deployment Status of the RPKI:

- Today: ROAs cover about 4% of interdomain routes.
- Goal: Cover all routes!

how relying parties sync to the RPKI [RFC 6480]



issue 1: RPKI authorities can unilaterally whack ROAs

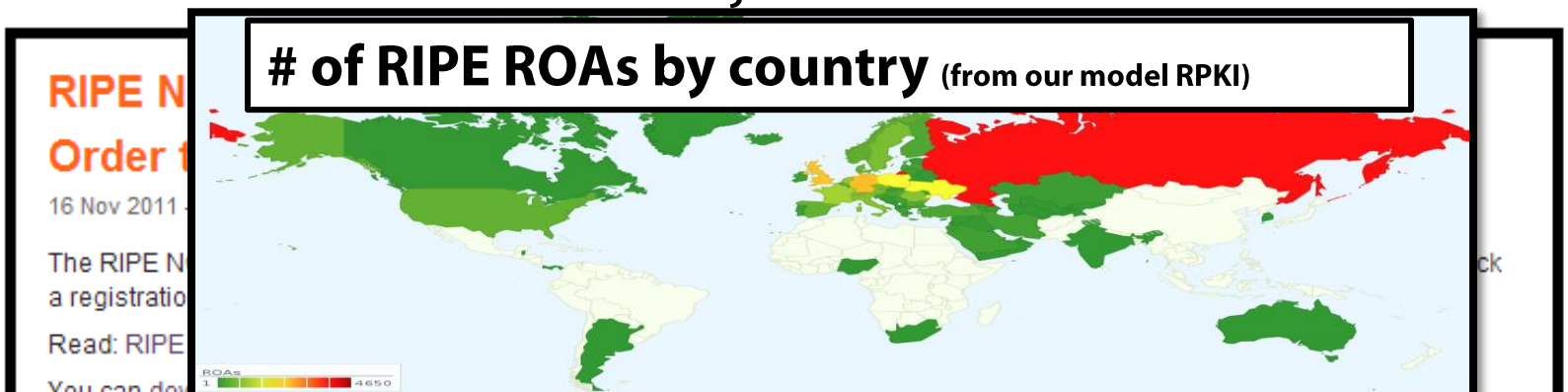


If routers "drop invalid " routes, they could lose connectivity to a legitimate route!

IP prefix takedowns by deleting ROAs?

- Prior to the RPKI, authorities could allocate IPs but not revoke them.
- But RPKI authorities **can** revoke IP allocations!
- Creates a risk that the RPKI can be used for unilateral takedowns.
  - Law enforcement? Business disputes? Extortion?
  - The RPKI designed to secure routing, not enable takedowns.
  - **[Mueller-Kuerbis'11, Mueller-Schmidt-Kuerbis'13, Amante'12, FCC'13,…]**

- States seem to want the ability to takedown IP prefixes…
  - Dutch court ordered RIPE to lockdown prefixes registration (Nov'11)
  - US court issued a writ of attachment on Iran's IP prefixes (June'14)
  - IP allocation does not reflect jurisdiction.



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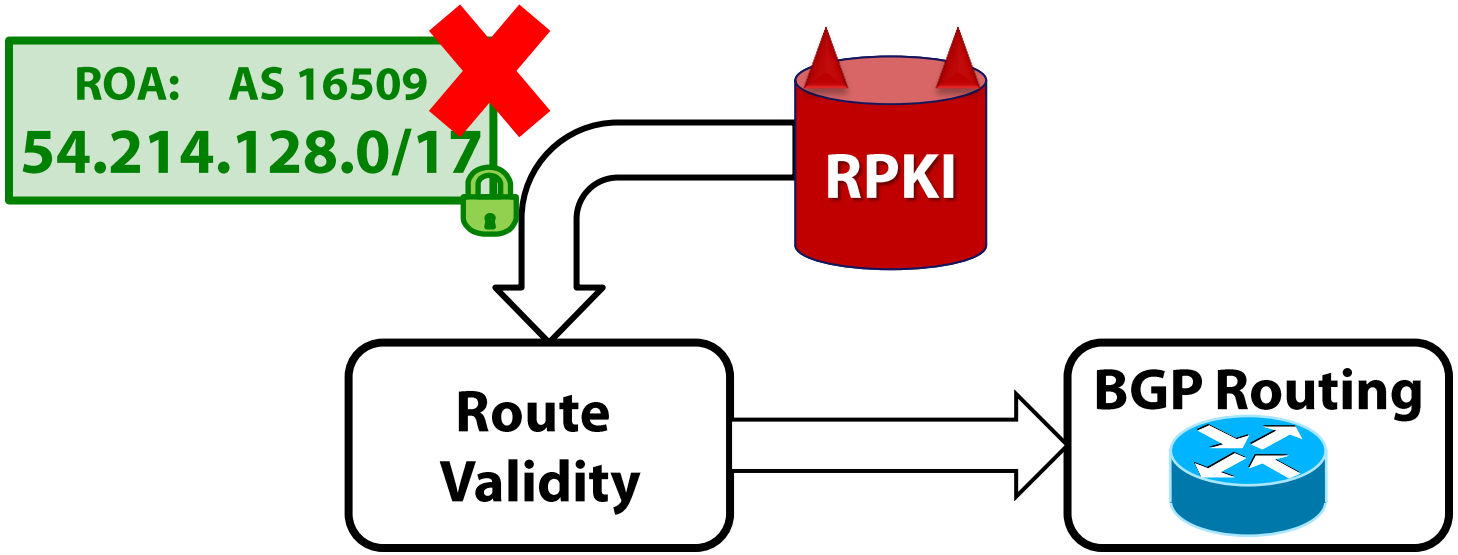

issue 2: whacked ROAs can cause BGP routes to be invalid

valid BGP route

invalid BGP route

unknown BGP route ← "World before RPKI"

Reality: interdependent validity outcomes

valid ROA → valid BGP route | invalid subroutes!

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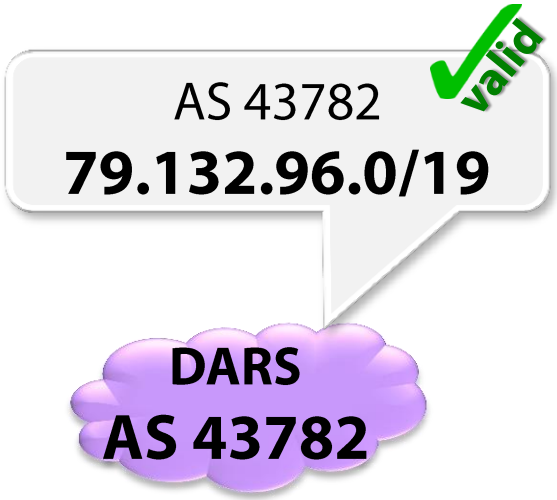

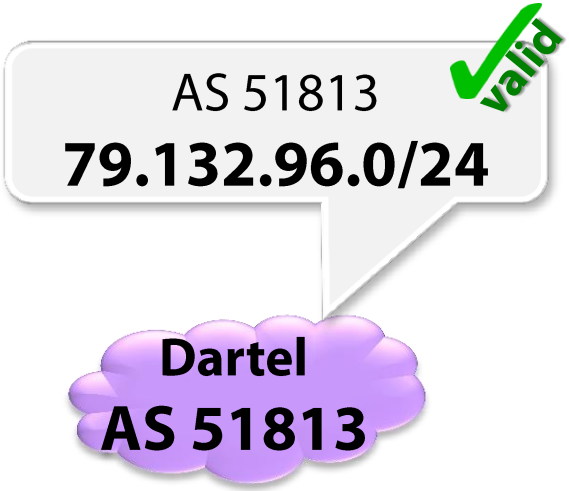

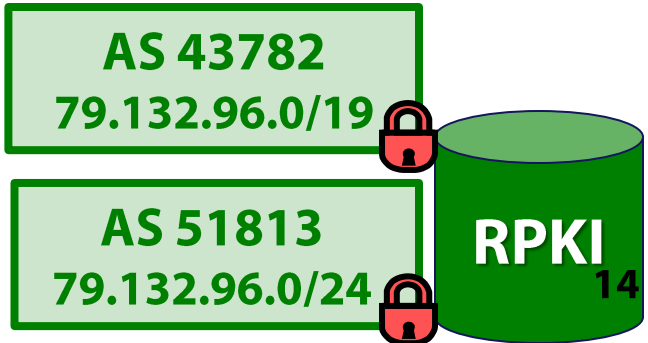

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invalid ROA or missing ROA	→	invalid BGP routes or unknown BGP routes	(if covering ROA)

AS 43782
79.132.96.0/19
valid

DARS
AS 43782

AS 51813
79.132.96.0/24

Dartel
AS 51813

AS 43782
79.132.96.0/19

RPKI

issue 2: whacked ROAs can cause BGP routes to be invalid

valid BGP route
invalid BGP route
unknown BGP route ← "World before RPKI"

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? unknown!

AS 51813
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valid

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RPKI

talk outline

- ☑ **Security audit of the RPKI [HotNets'13]**

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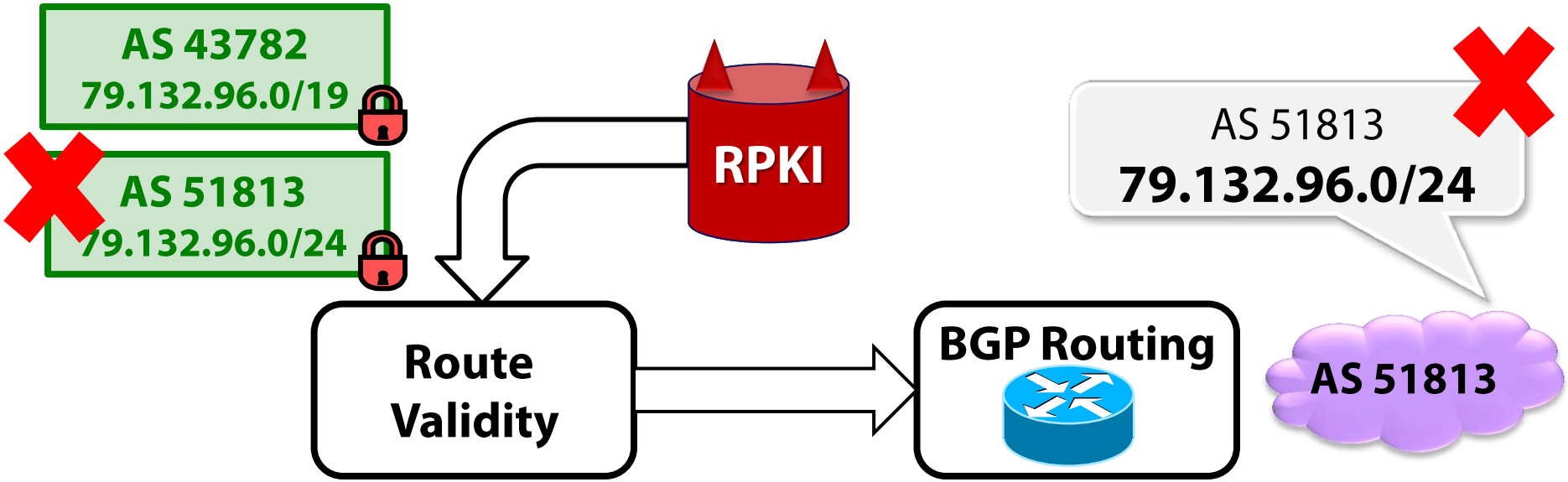
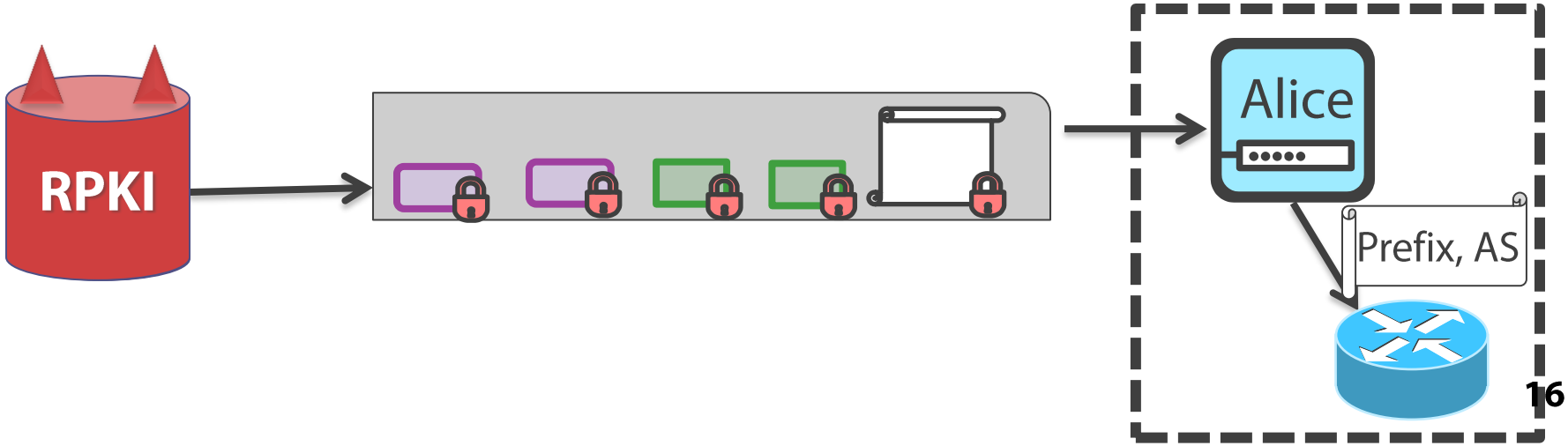


- ☐ **Proposal to require consent for whacked objects [SIGCOMM'14]**
  - There is a draft for similar proposal: **[draft-kent-sidr-suspenders-02]**

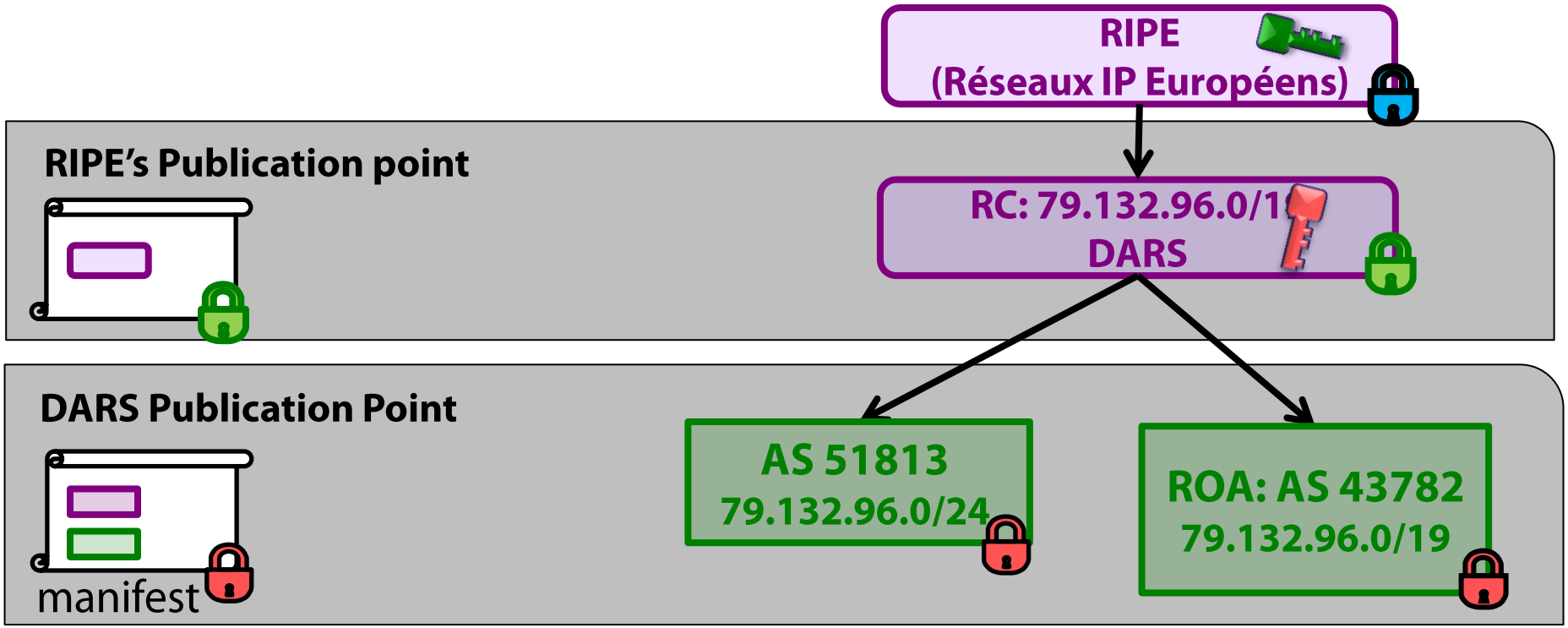
proposal: require consent to whack objects [SIGCOMM'14]

- **Design goals:**
  - **Consent**: Resource certs (RCs) must consent to be whacked.
  - **Transparency:** Relying parties audit RPKI & alarm on problems.
  - **Consistency**: Relying parties have consistent views of the RPKI.

- **Threat Model:**
  - Similar to certificate transparency **[RFC 6962]**
  - Relying parties honestly audit the RPKI
  - Everyone else (incl. RPKI authorities) is untrusted



how to consent? introducing .dead objects



If an authority wants to revoke IP prefixes from a child RC,
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*Descendants aren't always impacted by changes to the parent; ask me why later!

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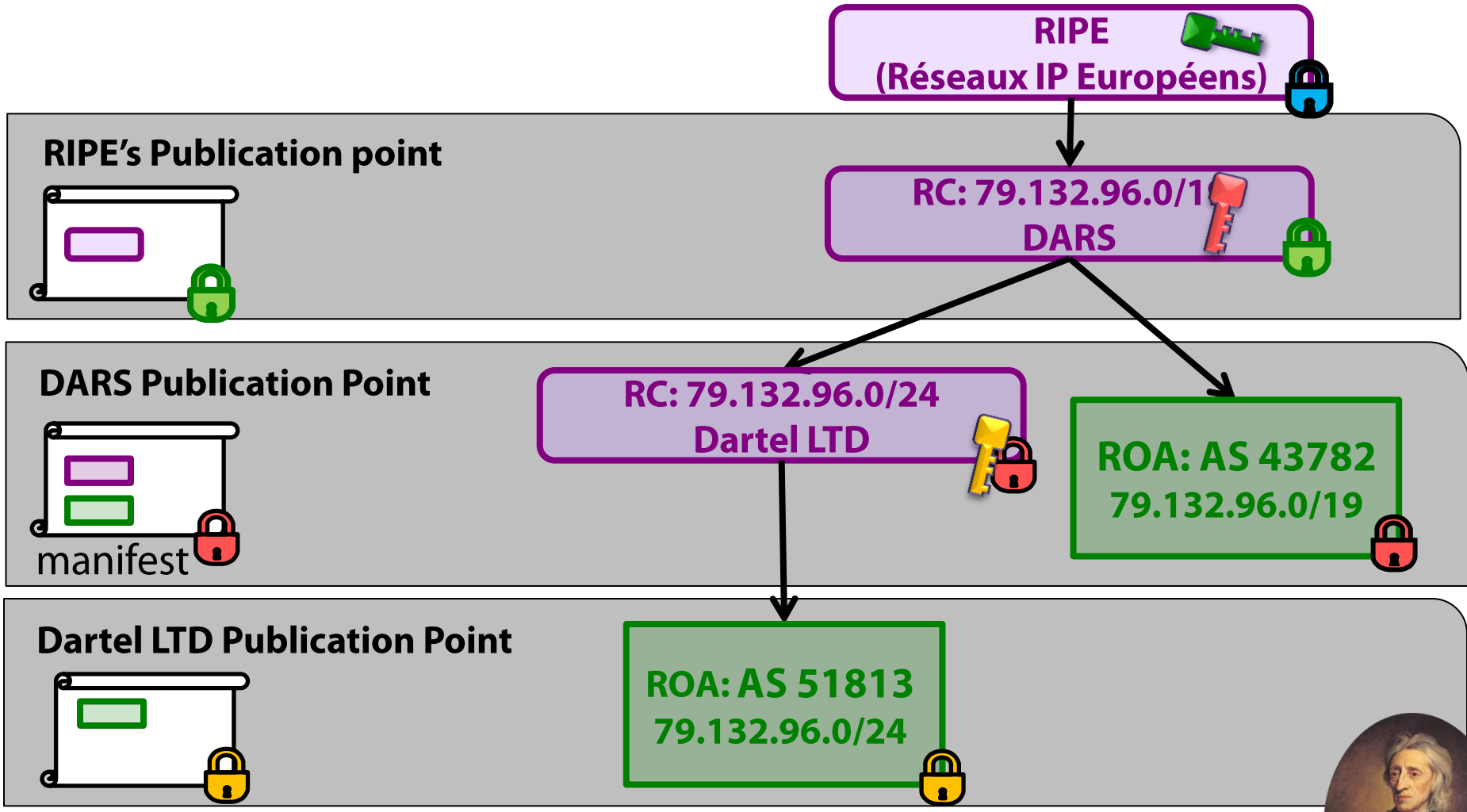

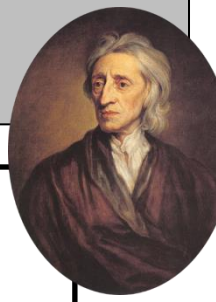

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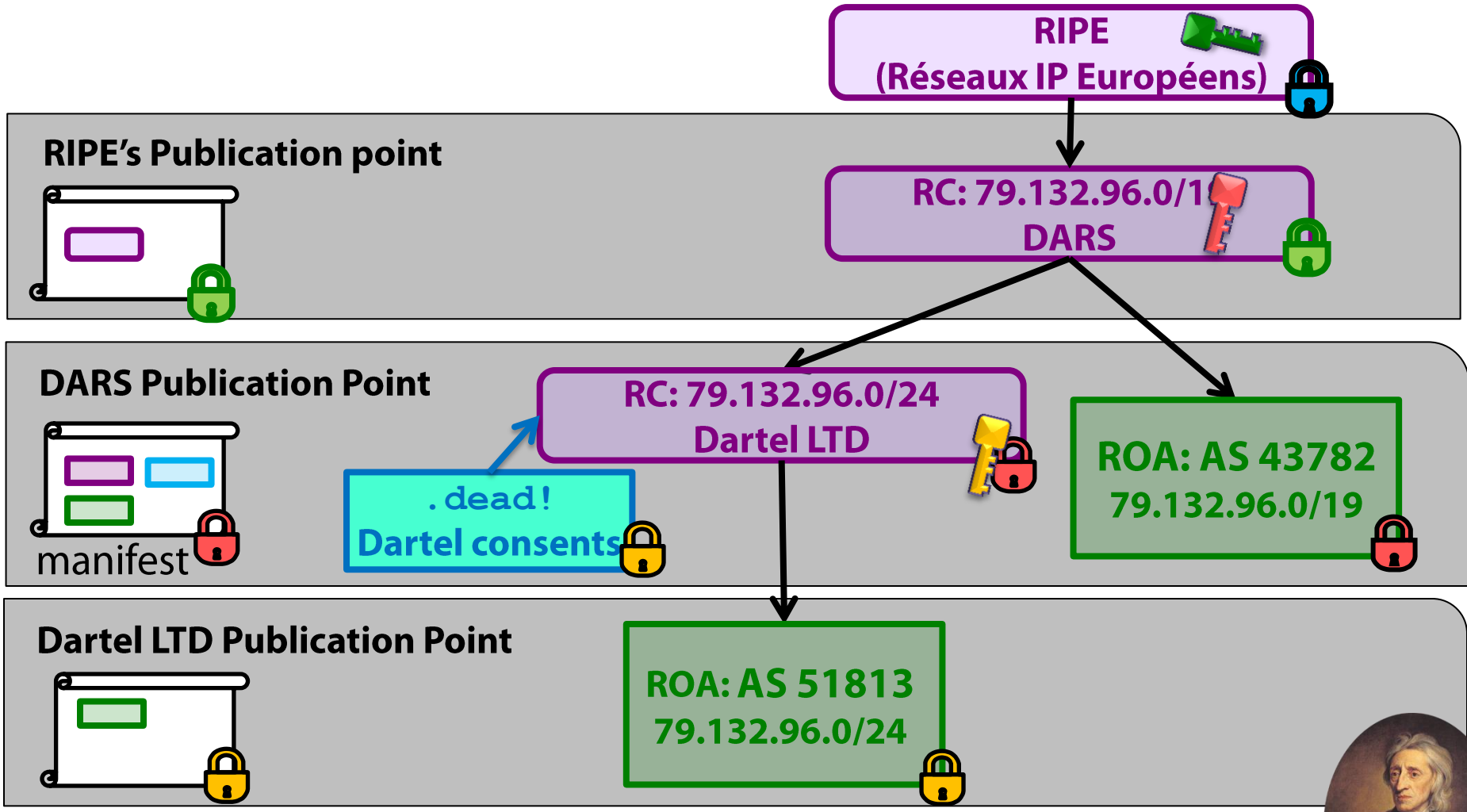

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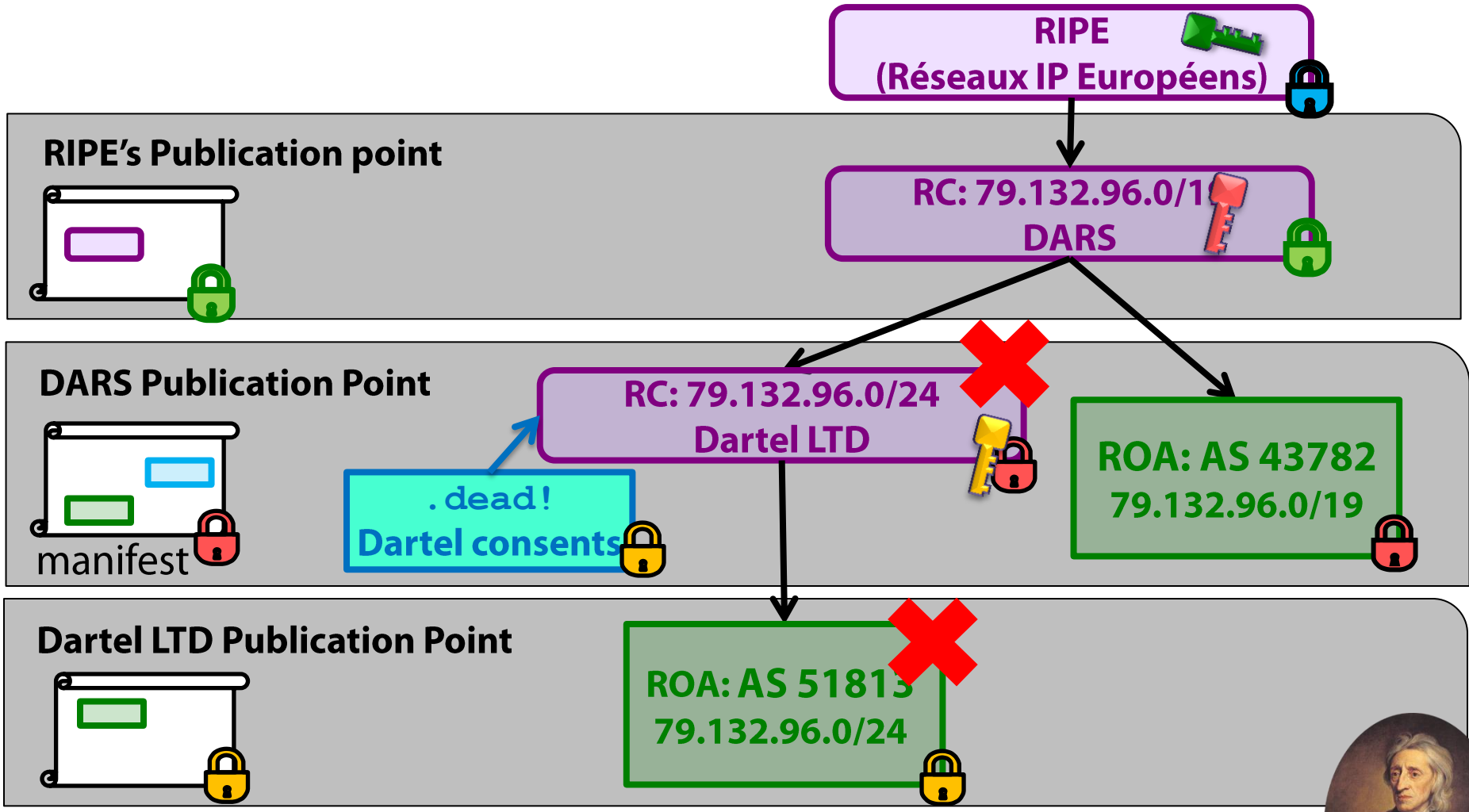

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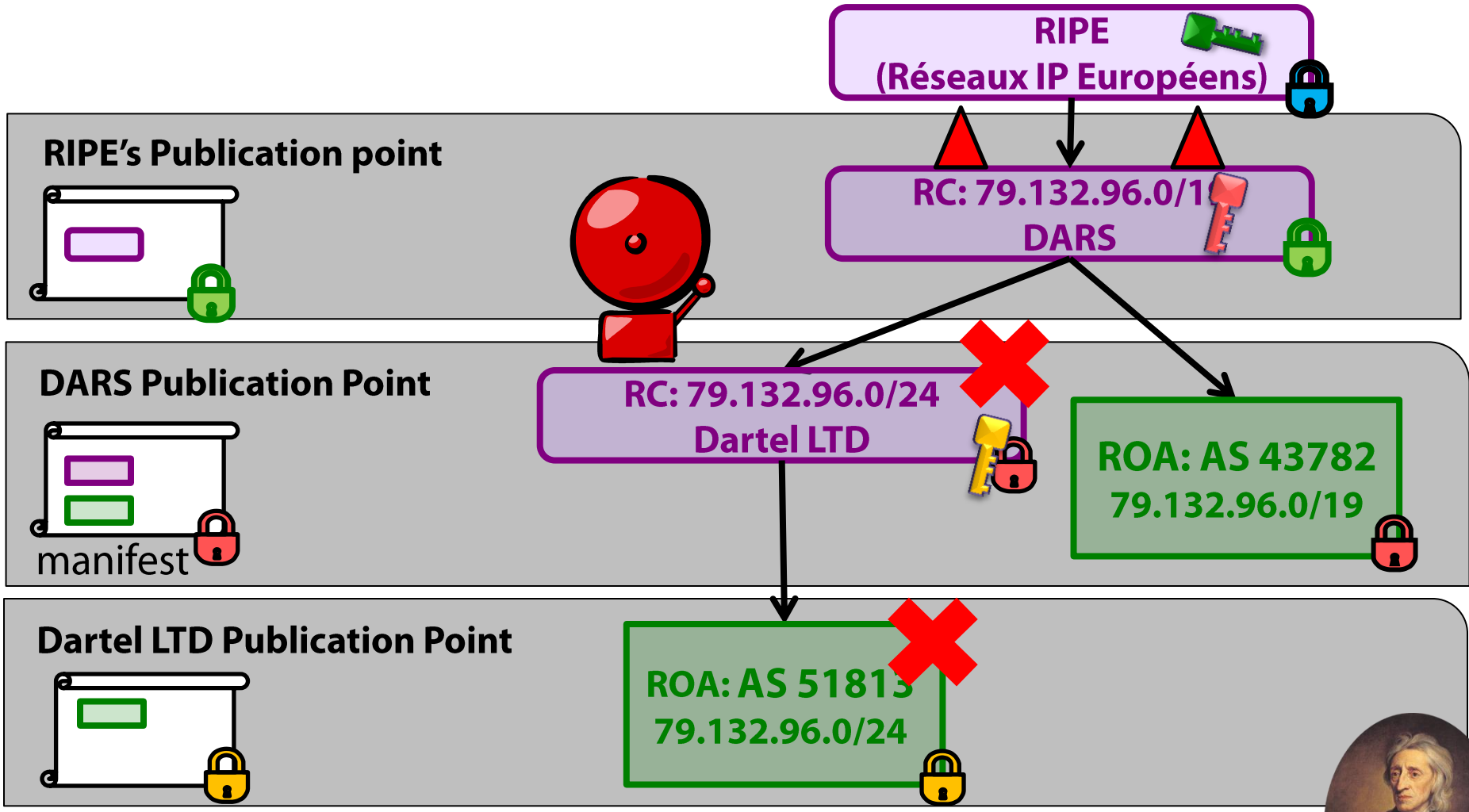

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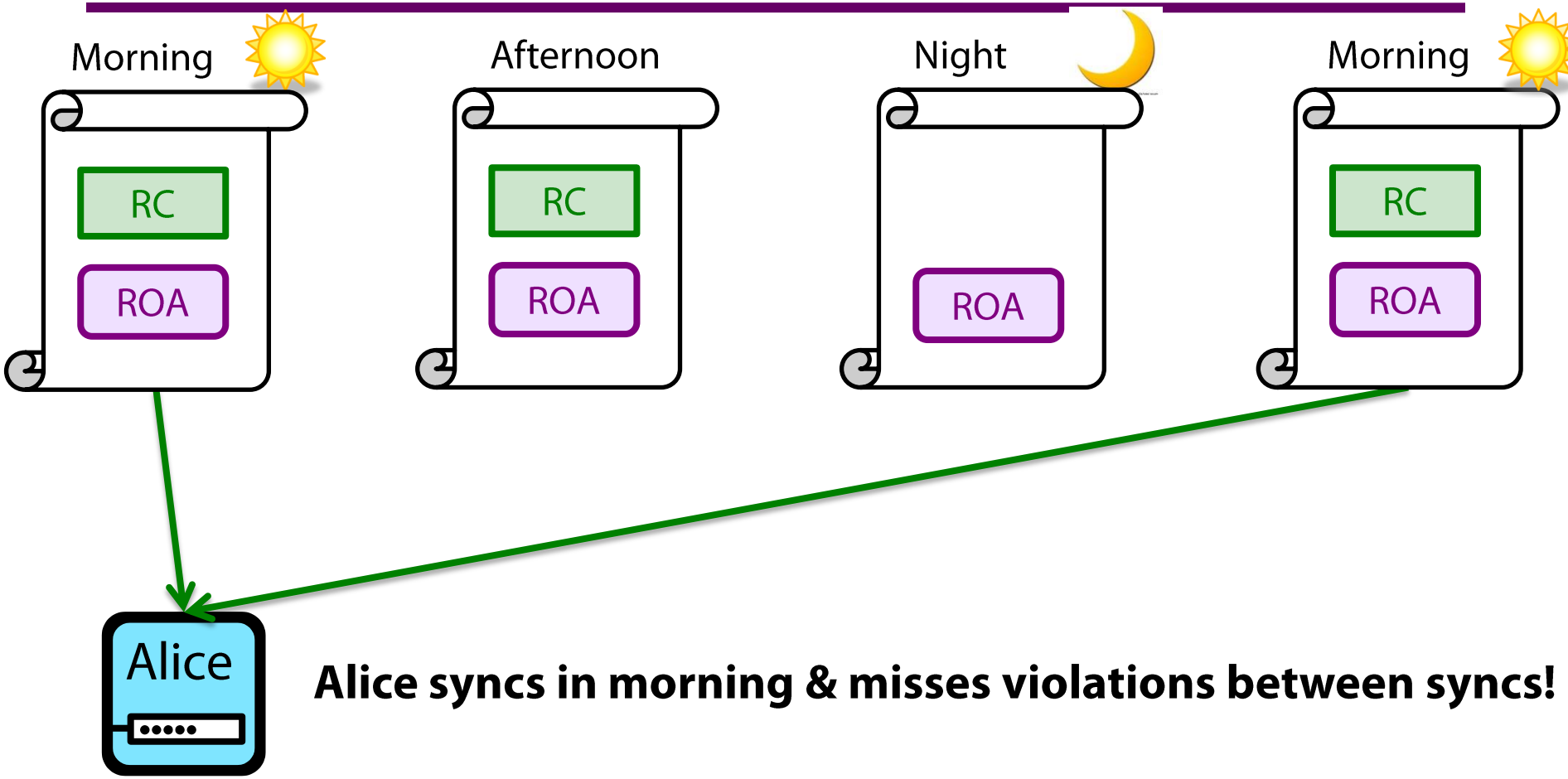
what about alarms between syncs?

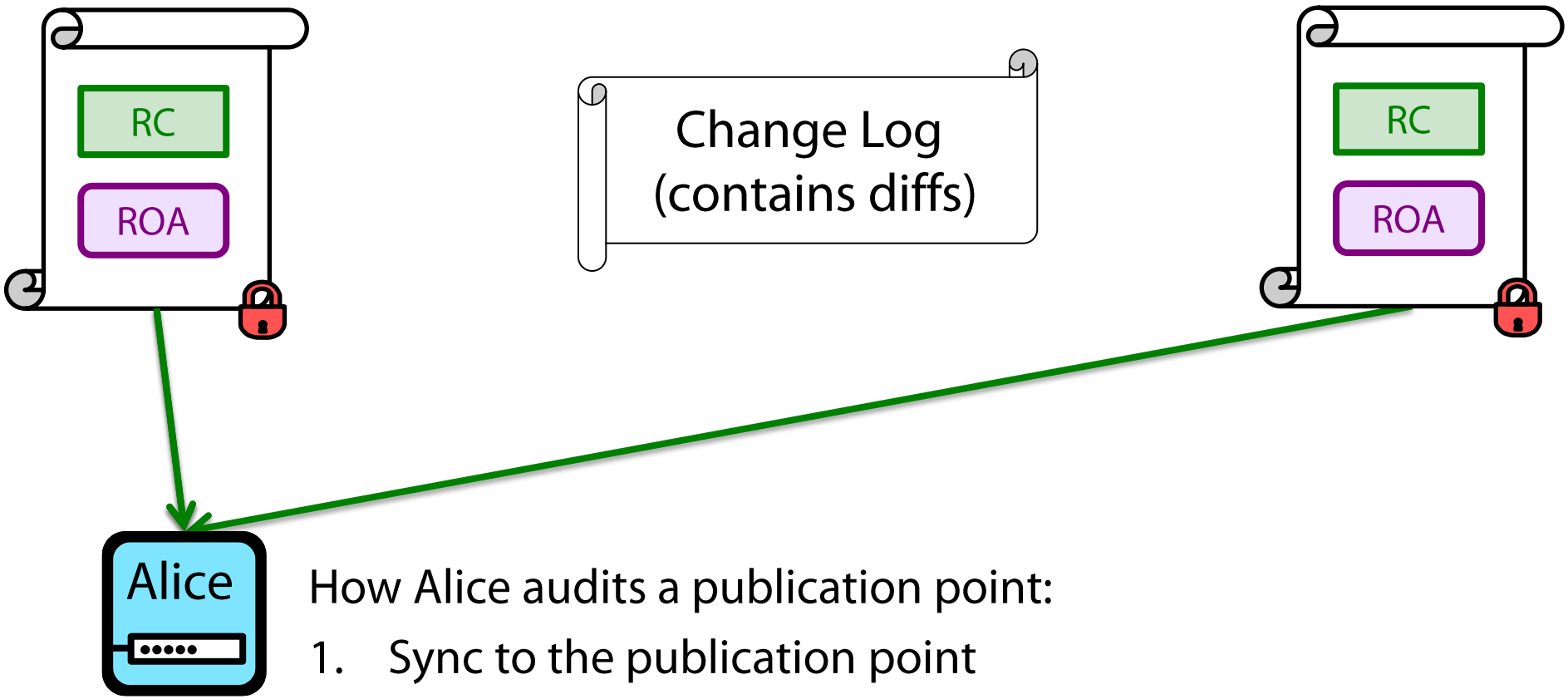


Alice syncs in morning & misses violations between syncs!

Why does Alice need to catch violations between syncs?

- So Alice can audit the RPKI
- So we can have consistency (explained later)

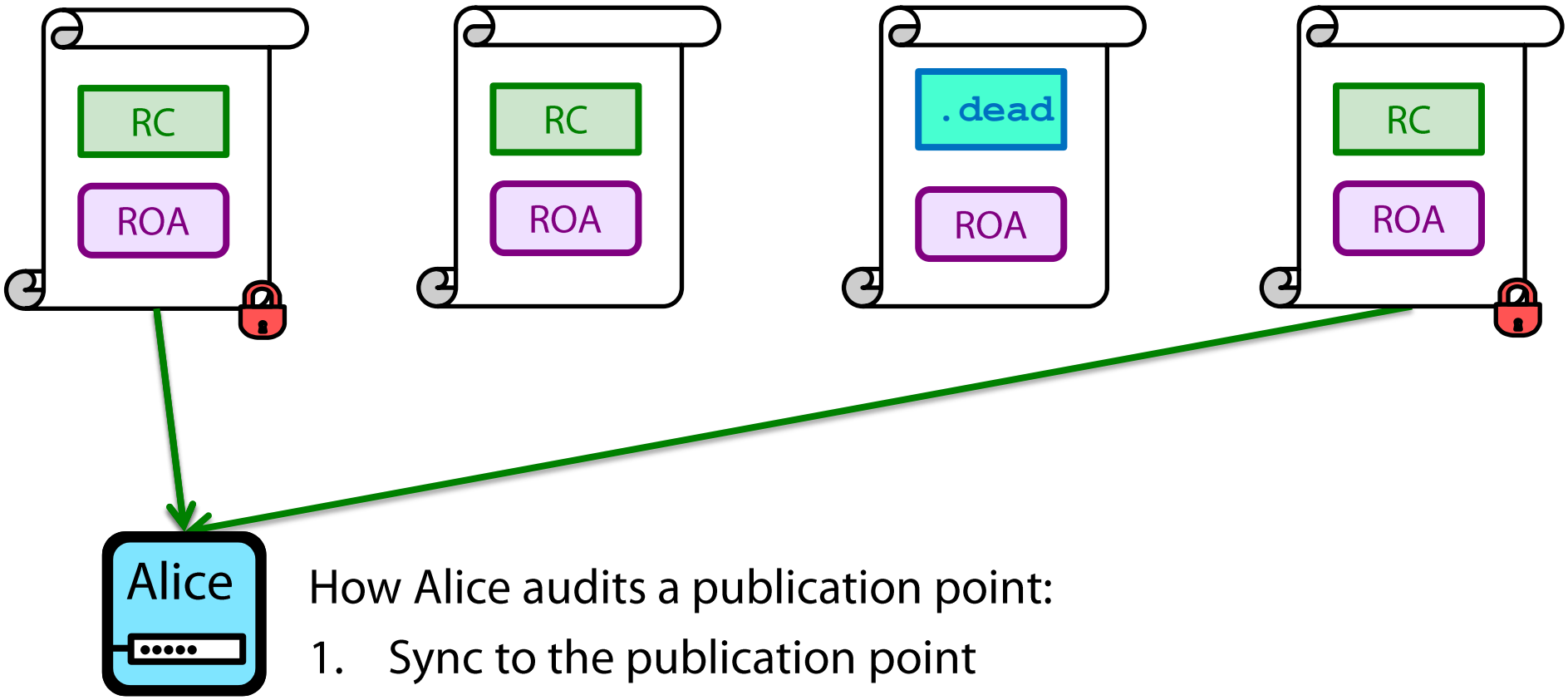
catching alarms between syncs!



How Alice audits a publication point:

1. Sync to the publication point
2. Use change log to reconstruct intermediate manifests

catching alarms between syncs!



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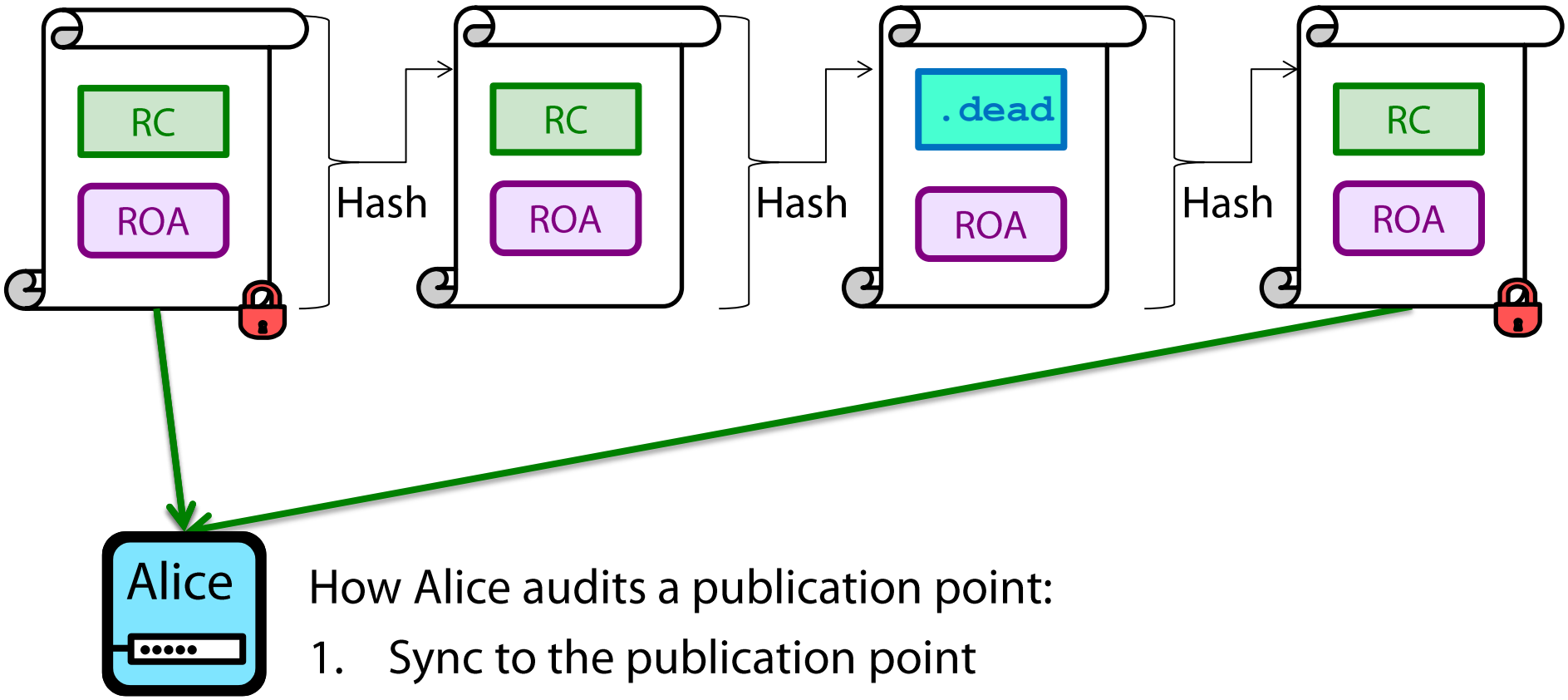

How Alice audits a publication point:

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3. Verify the hash chain & signature of the latest manifest
4. Alarm if a consent violation is detected.

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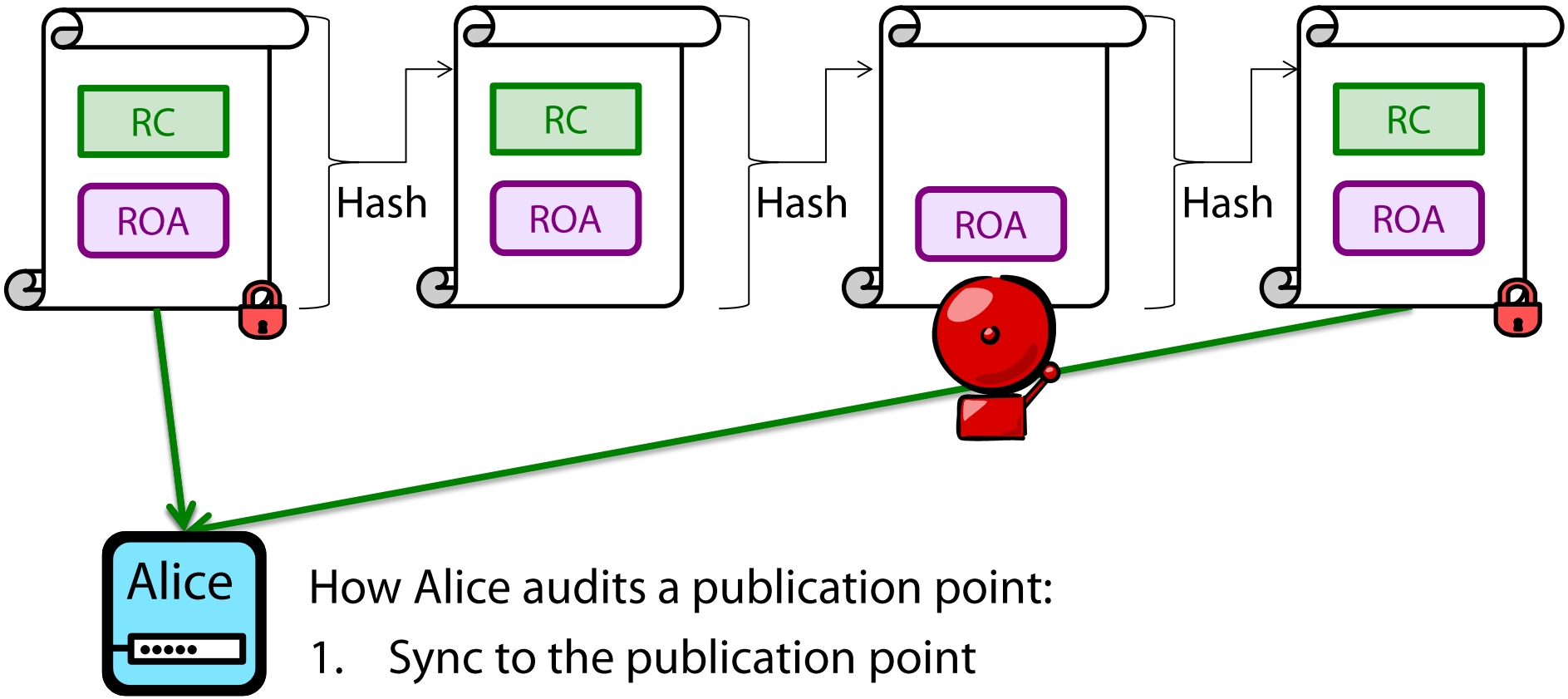

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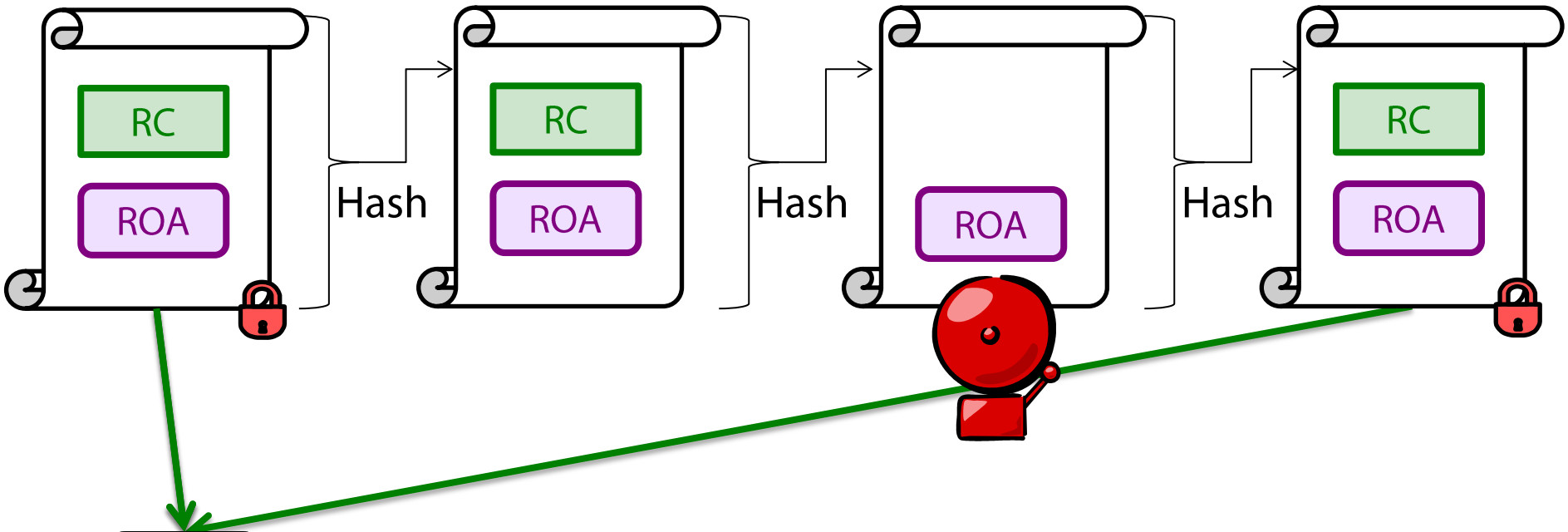

How Alice audits a publication point:

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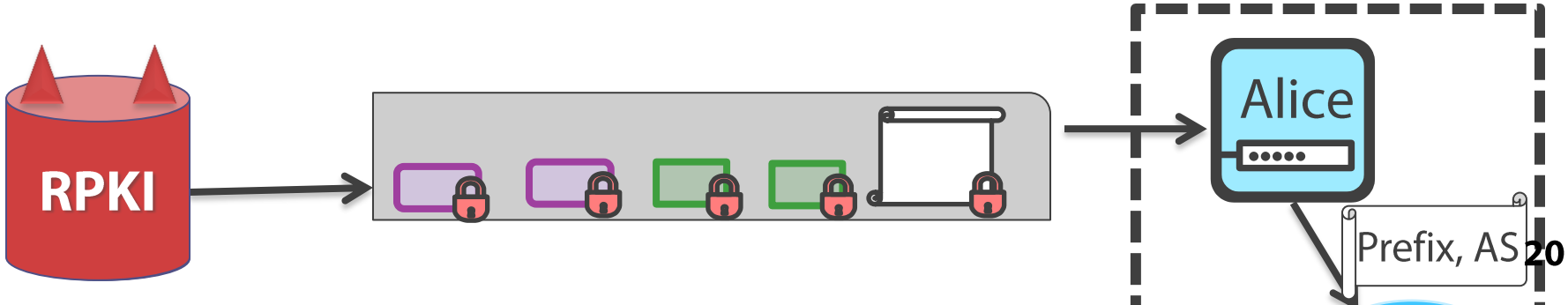
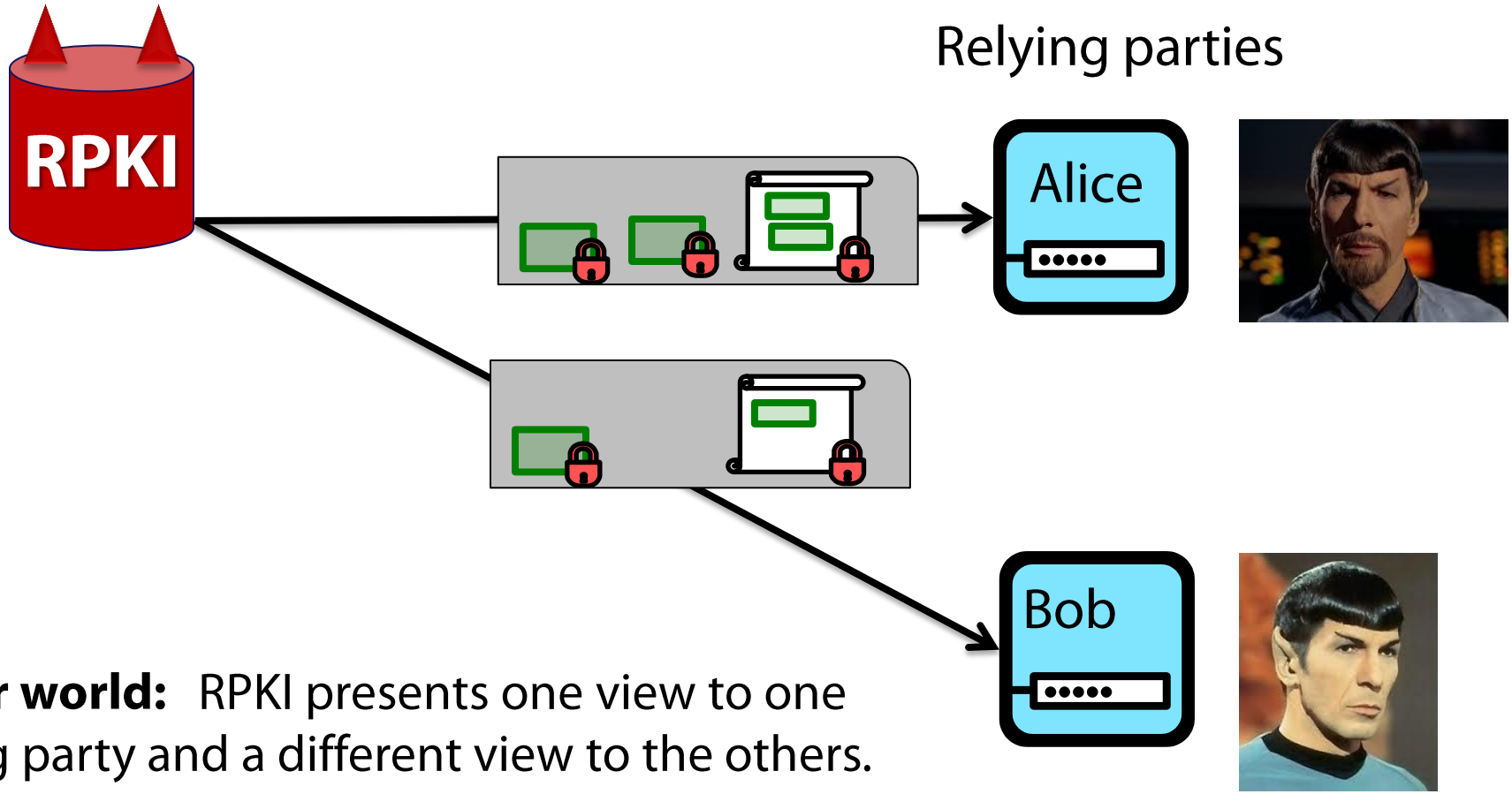
Valid Remains Valid. Our auditing algorithm makes sure that once a relying party has seen a valid resource cert (RC), that RC remains valid until it consents to be deleted/modified.

proposal : require consent to delete objects [SIGCOMM'14]

- **Design goals:**
  - **Consent**: **.dead** objects indicate consent to whack resource certs (RCs)
  - **Consistency**: Relying parties have consistent views of the RPKI.
  - **Transparency:** Relying parties audit RPKI & alarm on problems.
    - "Drop invalid" for prefixes that are not part of an alarm
    - Manually audit prefixes that are part of an alarm.



mirror worlds: inconsistent views of the RPKI

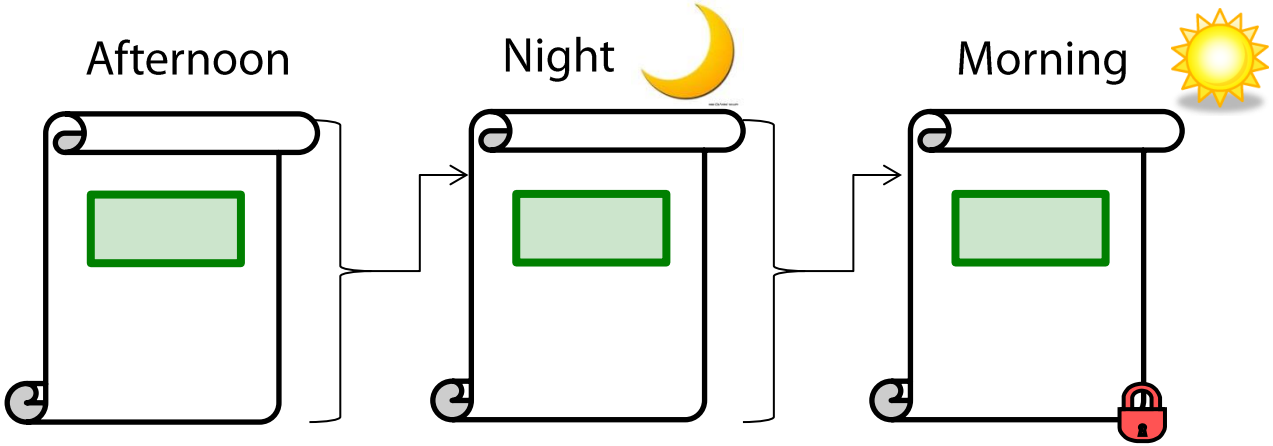


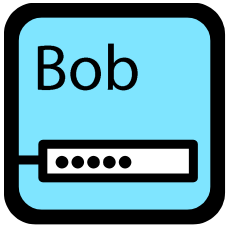
Mirror world: RPKI presents one view to one relying party and a different view to the others.

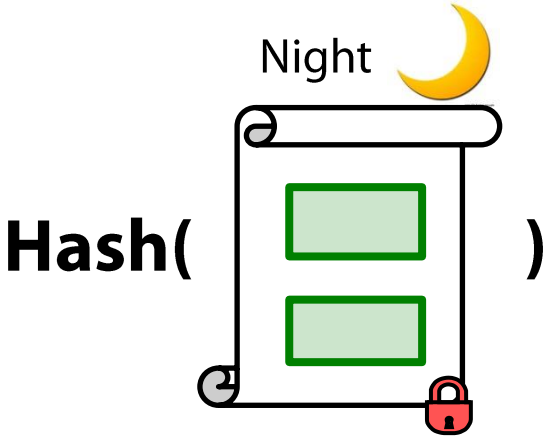
Why do we care?

- Auditing is less meaningful if Alice's view is different from everyone else's.
- Eg. Suppose Alice audits the RPKI to make sure her own ROAs are OK.

detecting mirror worlds using manifest hash chains







Bob sends a hash of his latest manifest & Alice finds it in her hashchain.

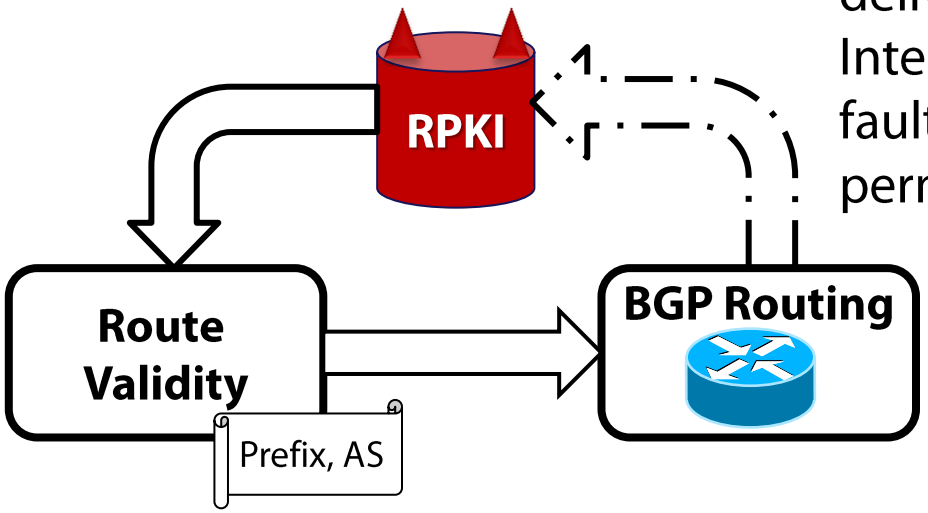
No mirror worlds!
If the consistency check passes, relying parties saw the same valid objects.

outline

Part 1: security audit of the RPKI [HotNets'13]

we need to harden the RPKI's delivery mechanism!

- eg. expired **[draft-ietf-sidr-multiple-publication-points-01]**



RPKI objects are delivered over the Internet; transient faults can cause permanent errors

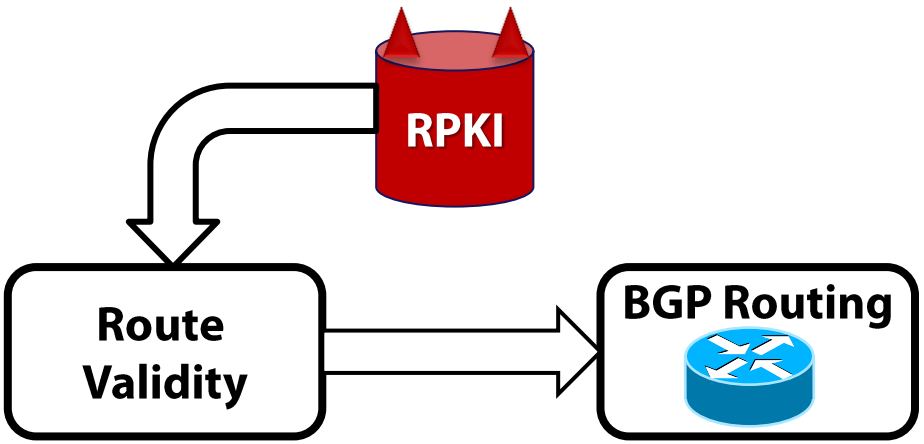
Part 2: proposal to improve RPKI transparency [SIGCOMM'14]

- There is a draft for similar proposal: **[draft-kent-sidr-suspenders-02]**

conclusion: more work needed

1. Robust delivery of RPKI objects from repos. **[To do!]**
2. Prevent misconfigured ROAs using config tools:
   1. RIPE RPKI management UI: **http://localcert.ripe.net:8088/**
   2. NIST RPKI deployment monitor: **http://rpki-monitor.antd.nist.gov/**
   3. RTRlib: **http://page.mi.fu-berlin.de/waehl/publications/whss-roslr-13.html**
   4. LACNIC RPKI looking glass: **www.labs.lacnic.net/rpkitools/looking_glass/**
   5. rcynic web interface
3. Limit risk of unilateral RPKI takedowns. **[To do!]**
   1. Our proposal **[SIGCOMM'14]**
   2. **[draft-kent-sidr-suspenders-02]**
4. React to RPKI alarms with nuanced routing policies. **[To do!]**

Thanks! Project page:
http://www.cs.bu.edu/~goldbe/papers/RPKImanip.html



questions

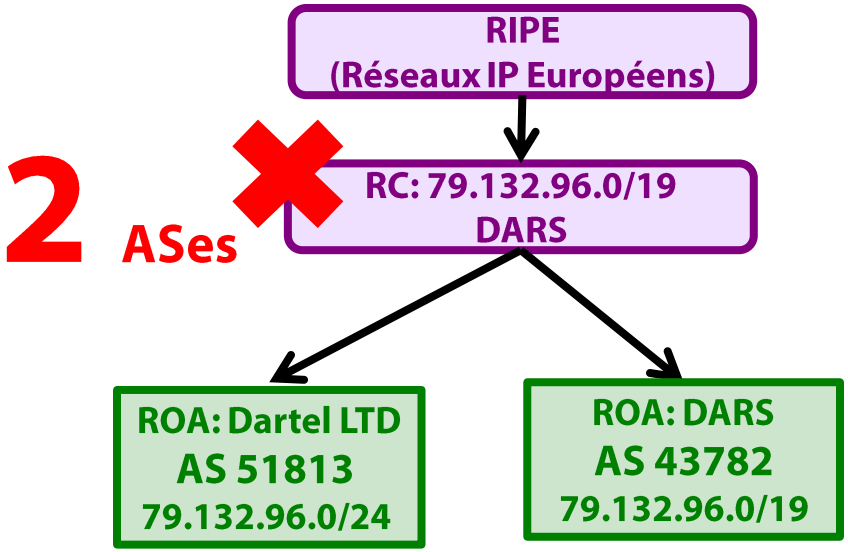
?

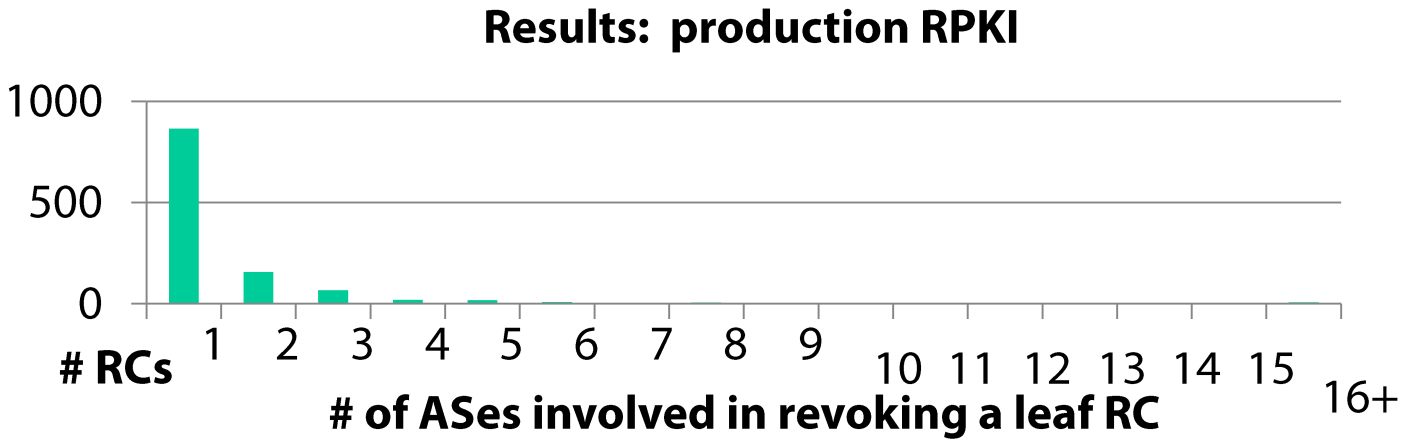
how many parties need to consent?

- How many ASes need to be involved when a leaf resource cert is revoked?

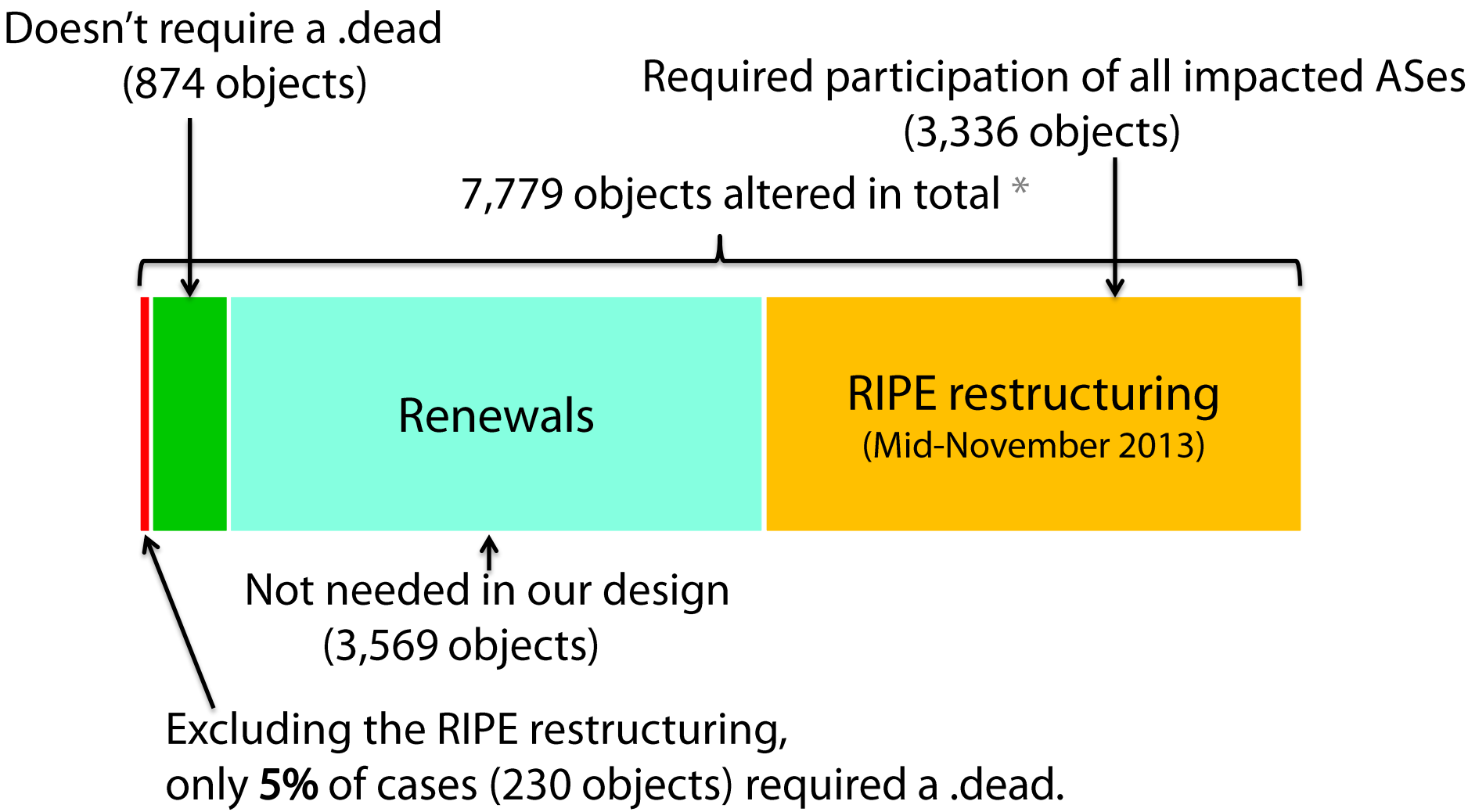
- Production RPKI
  - average **1.5** ASes / leaf RC

- Model fully-deployed RPKI
  - average **1.6** ASes / leaf RC
  - **99.3%** need **<10** ASes / leaf RC
  - **0.02%** need **>100** ASes / leaf RC





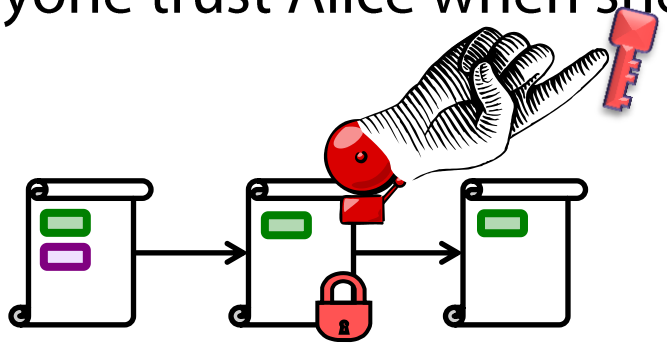
How often does would the RPKI need .deads?



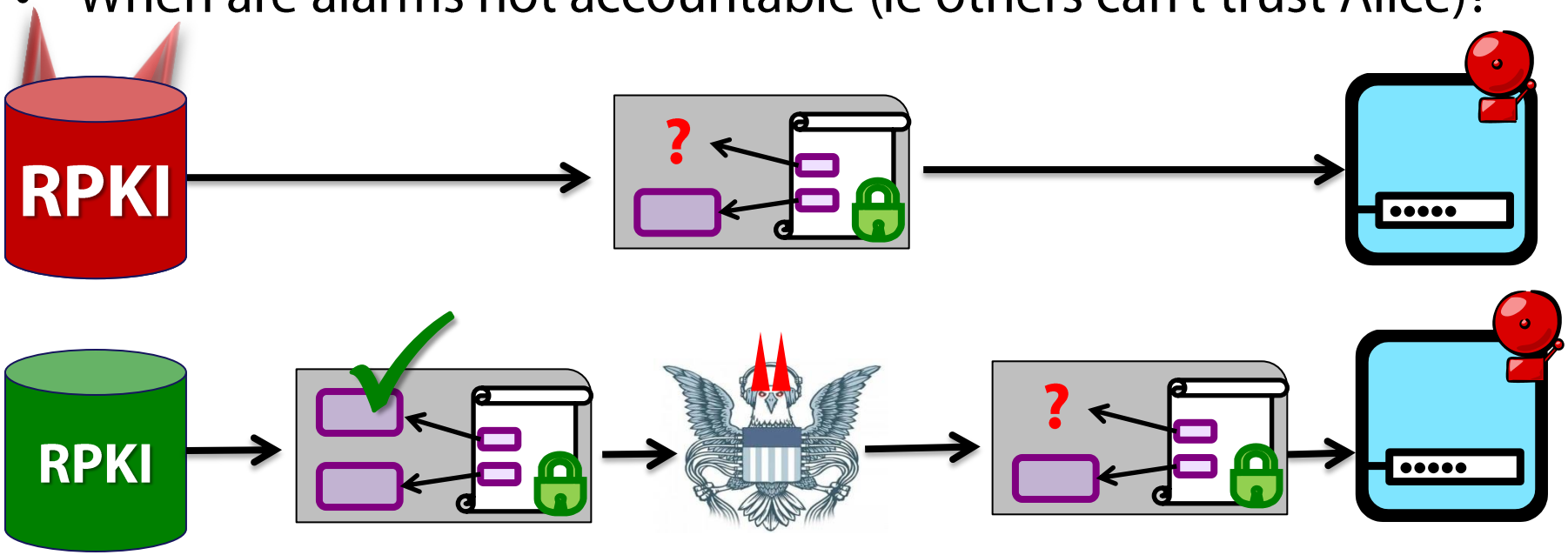
* all data from a ~3 month trace of the taken RPKI 2013/10/23 to 2014/01/21

Blaming authorities with accountable alarms.

- Why should anyone trust Alice when she raises an alarm?

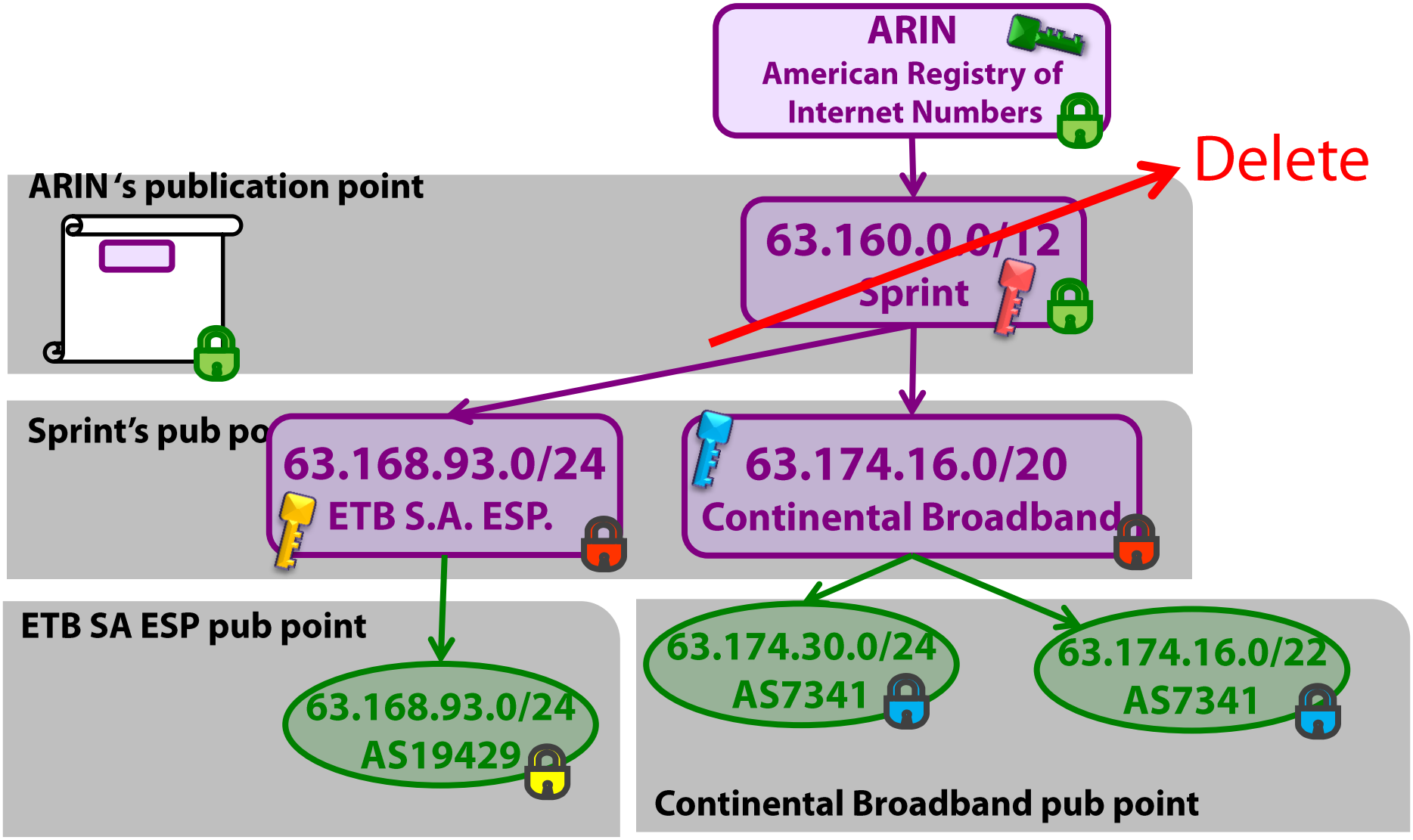


- When are alarms not accountable (ie others can't trust Alice)?

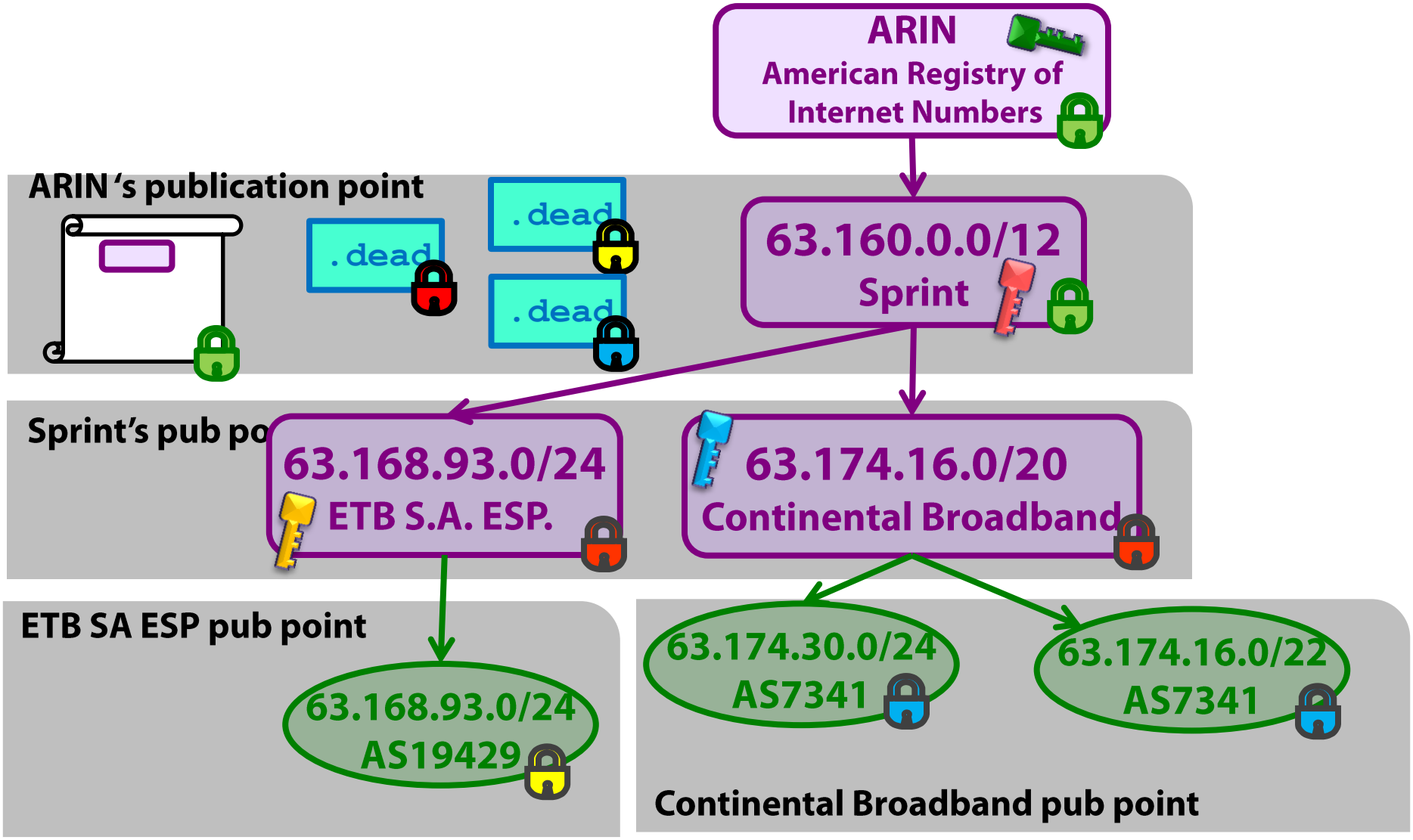


Alarms are accountable in every circumstance other than missing information.

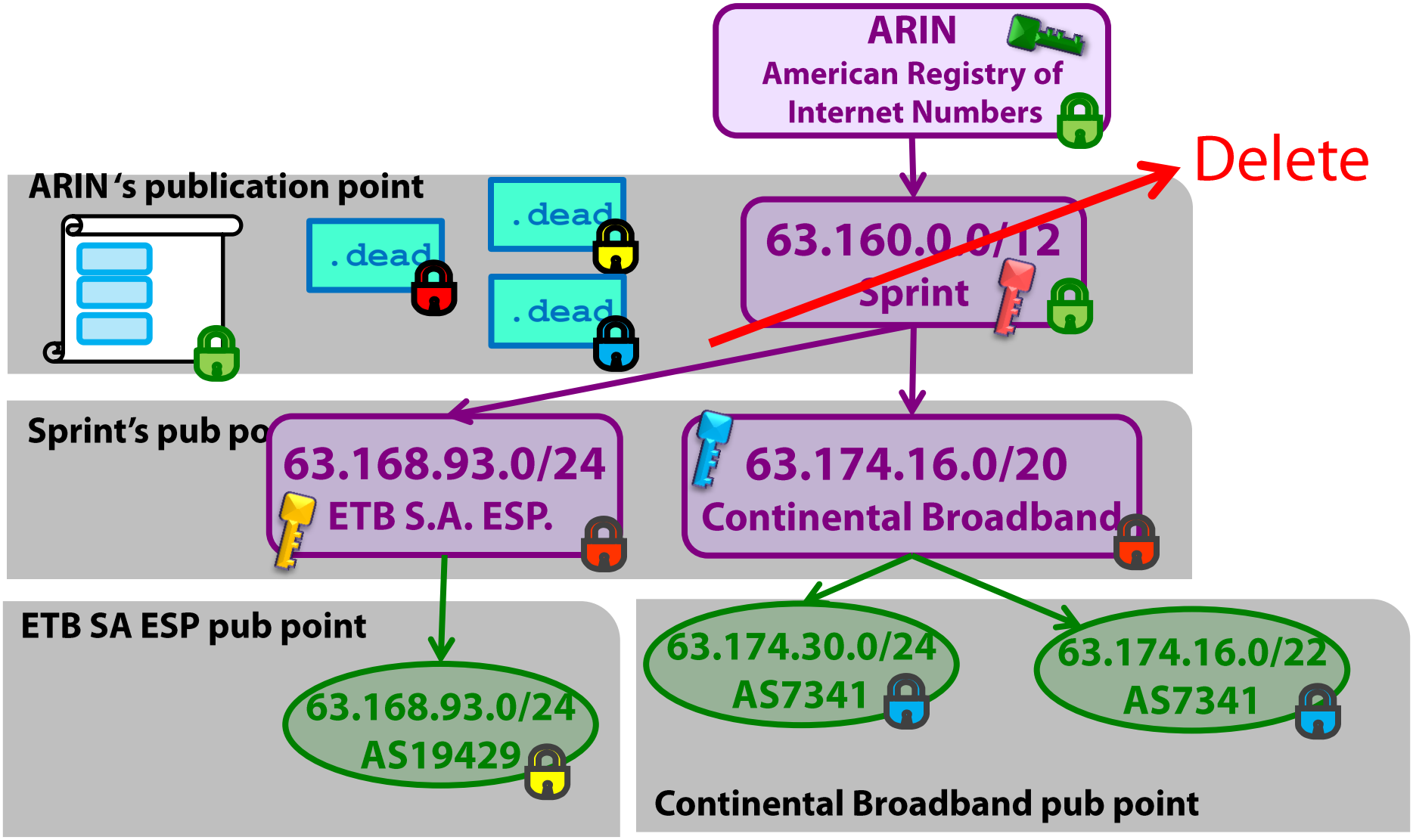
consent in a deep hierarchy: deletion



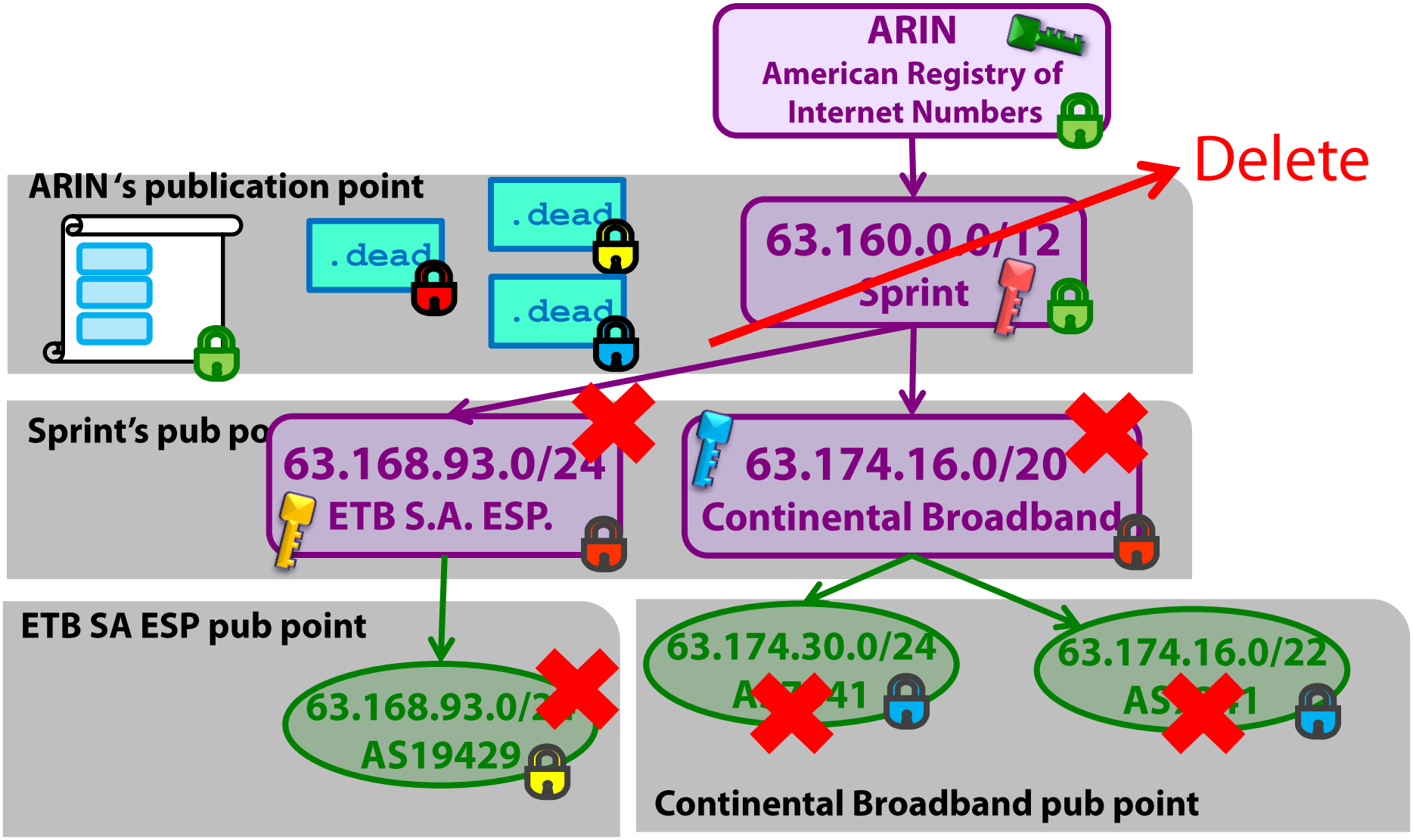
consent in a deep hierarchy: deletion



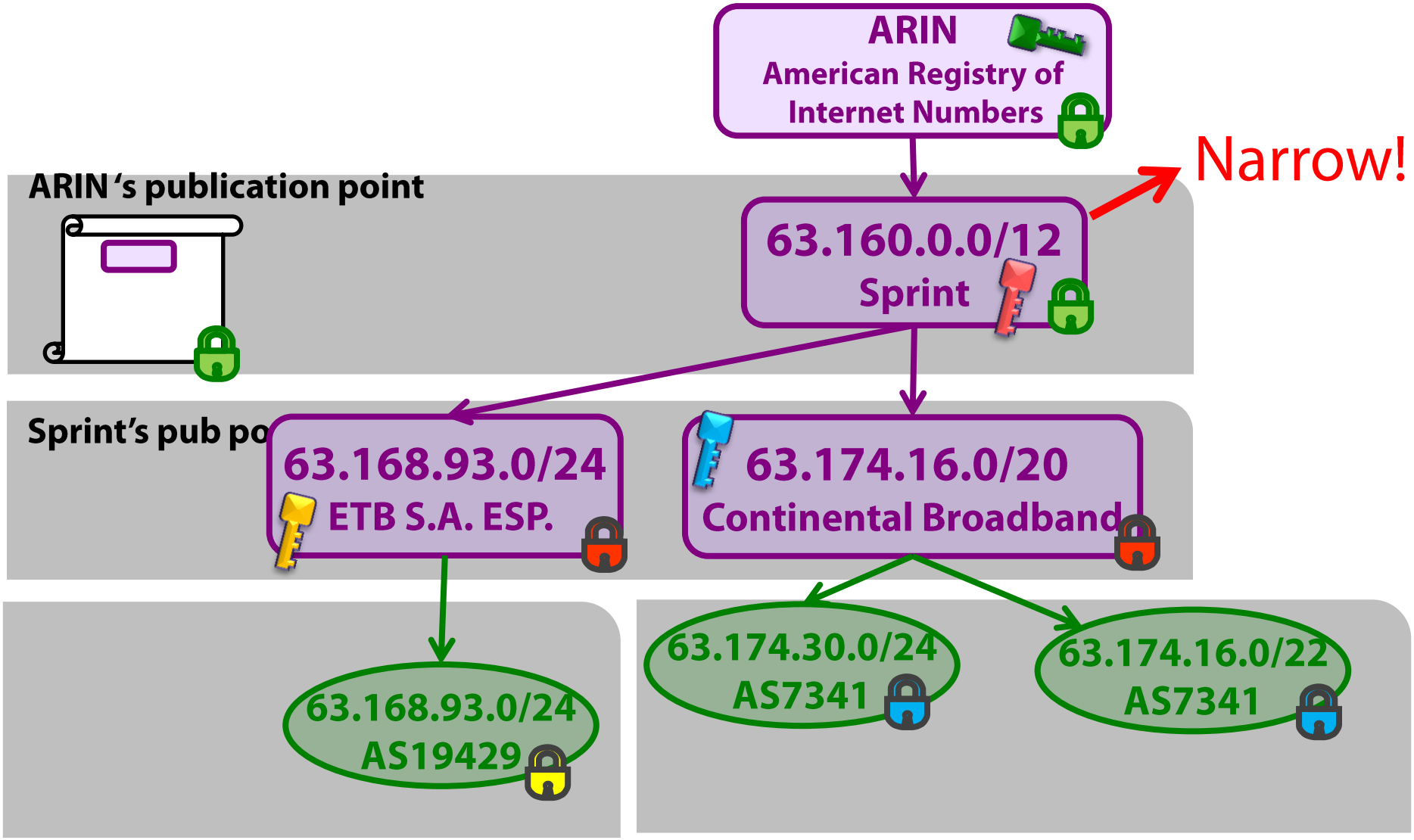
consent in a deep hierarchy: deletion



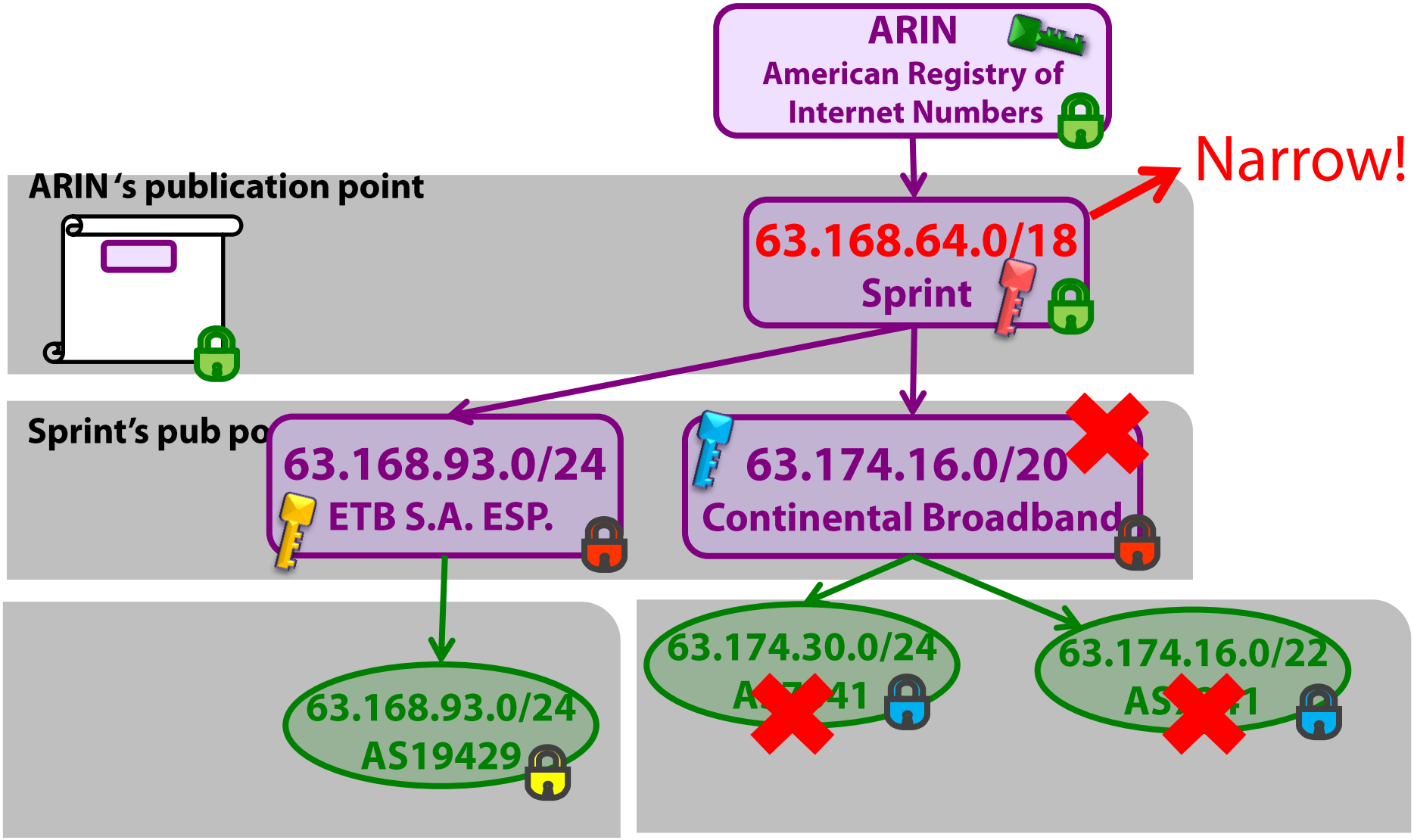
consent in a deep hierarchy: deletion



consent in a deep hierarchy: "address block narrowing"



consent in a deep hierarchy: "address block narrowing"



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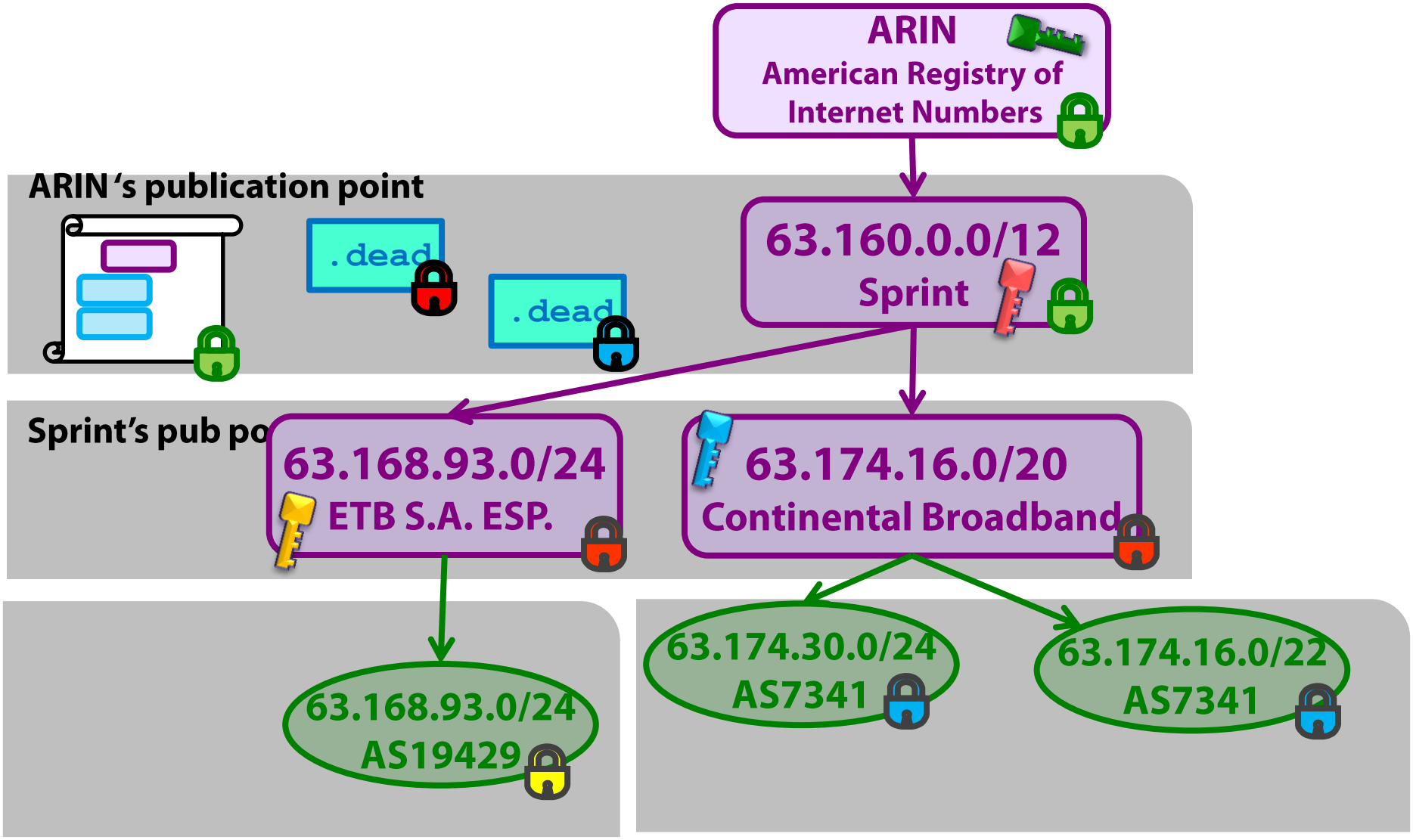

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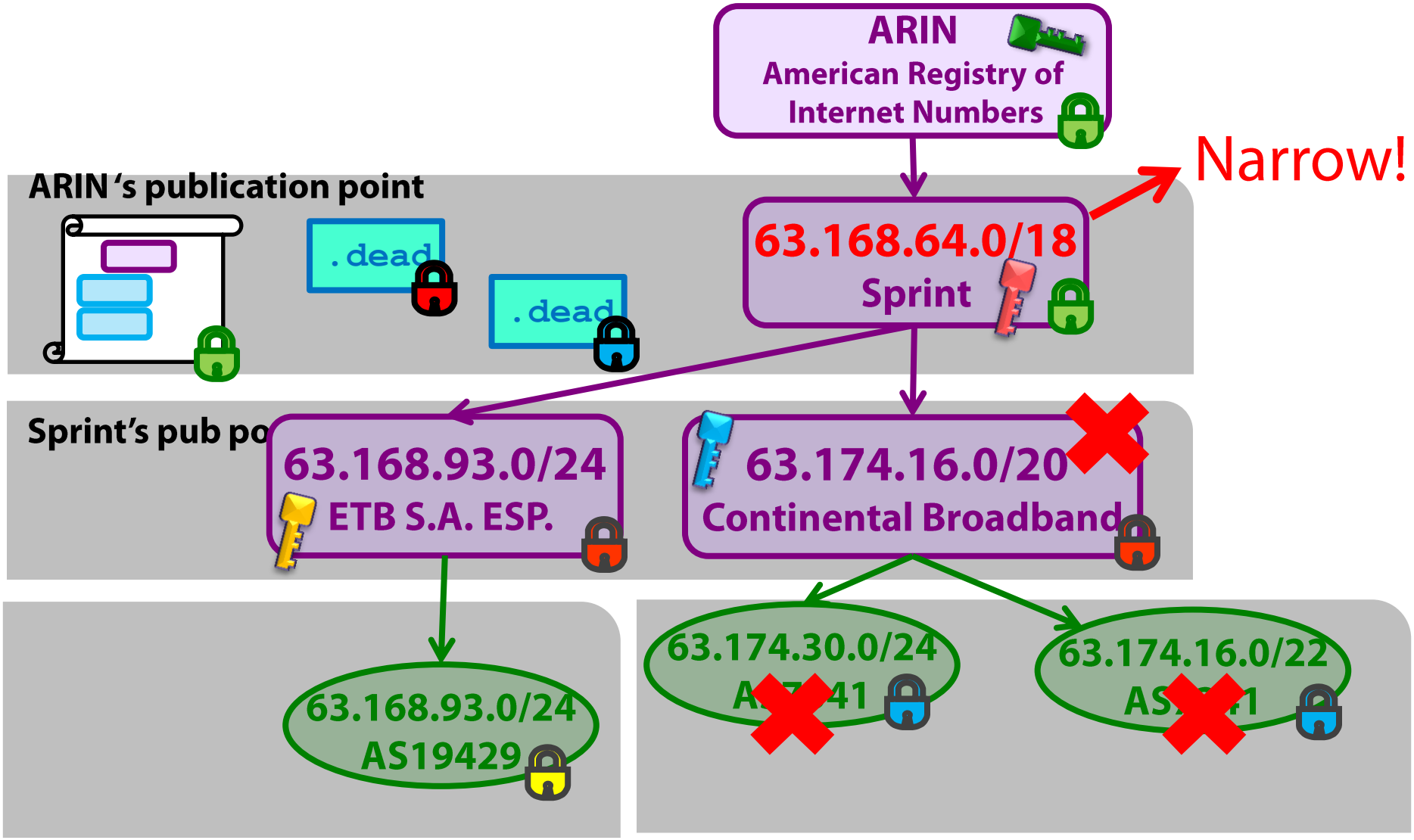
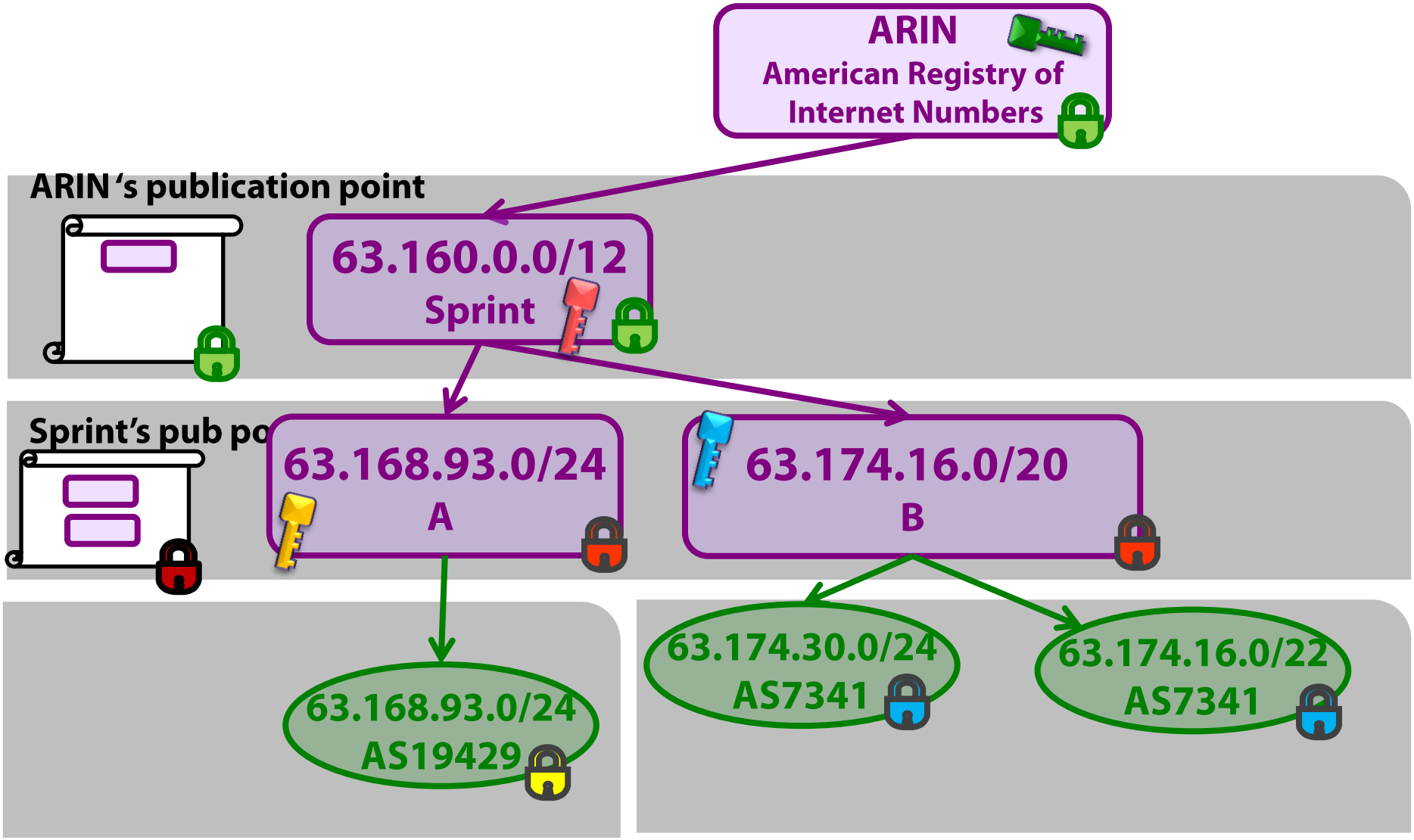
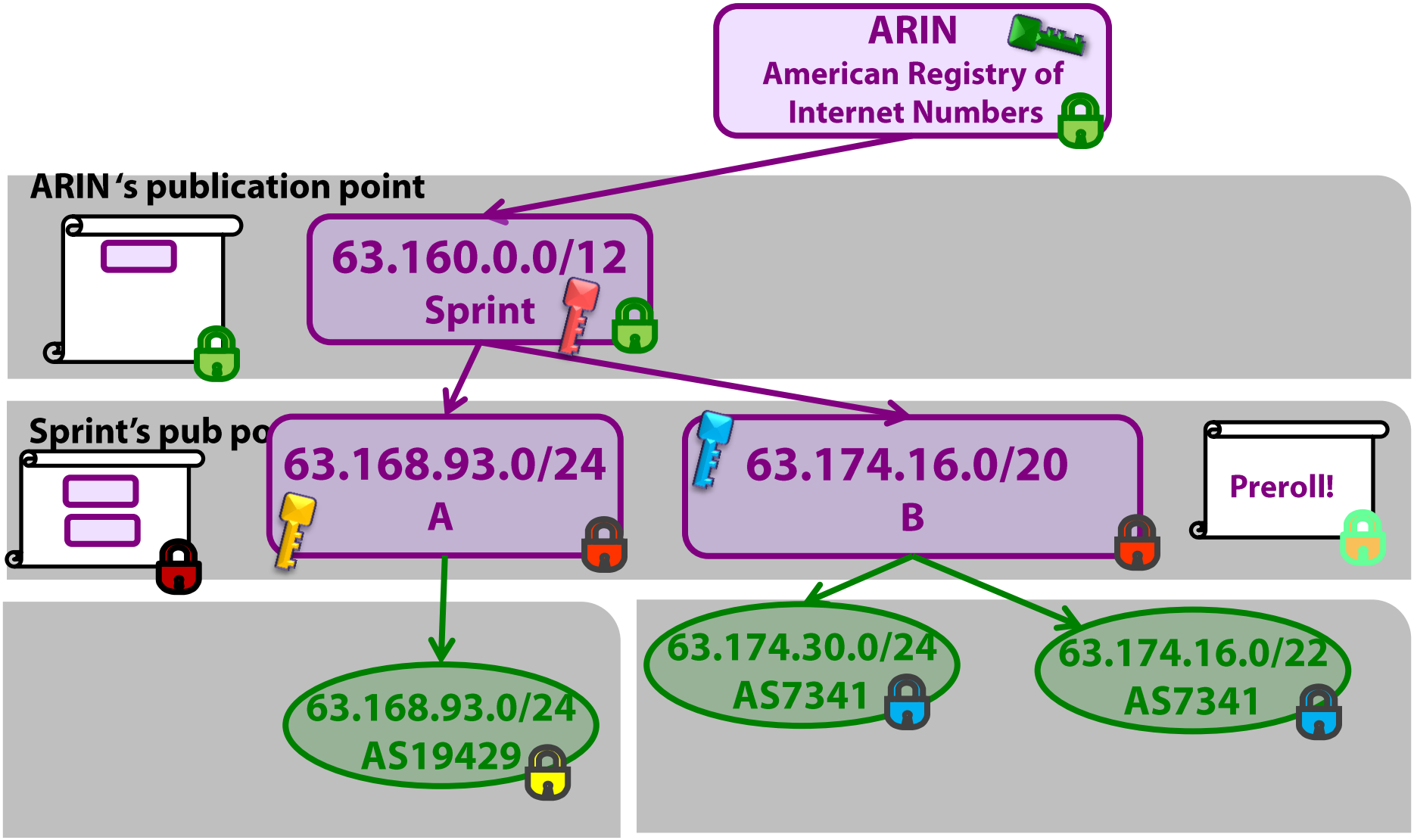


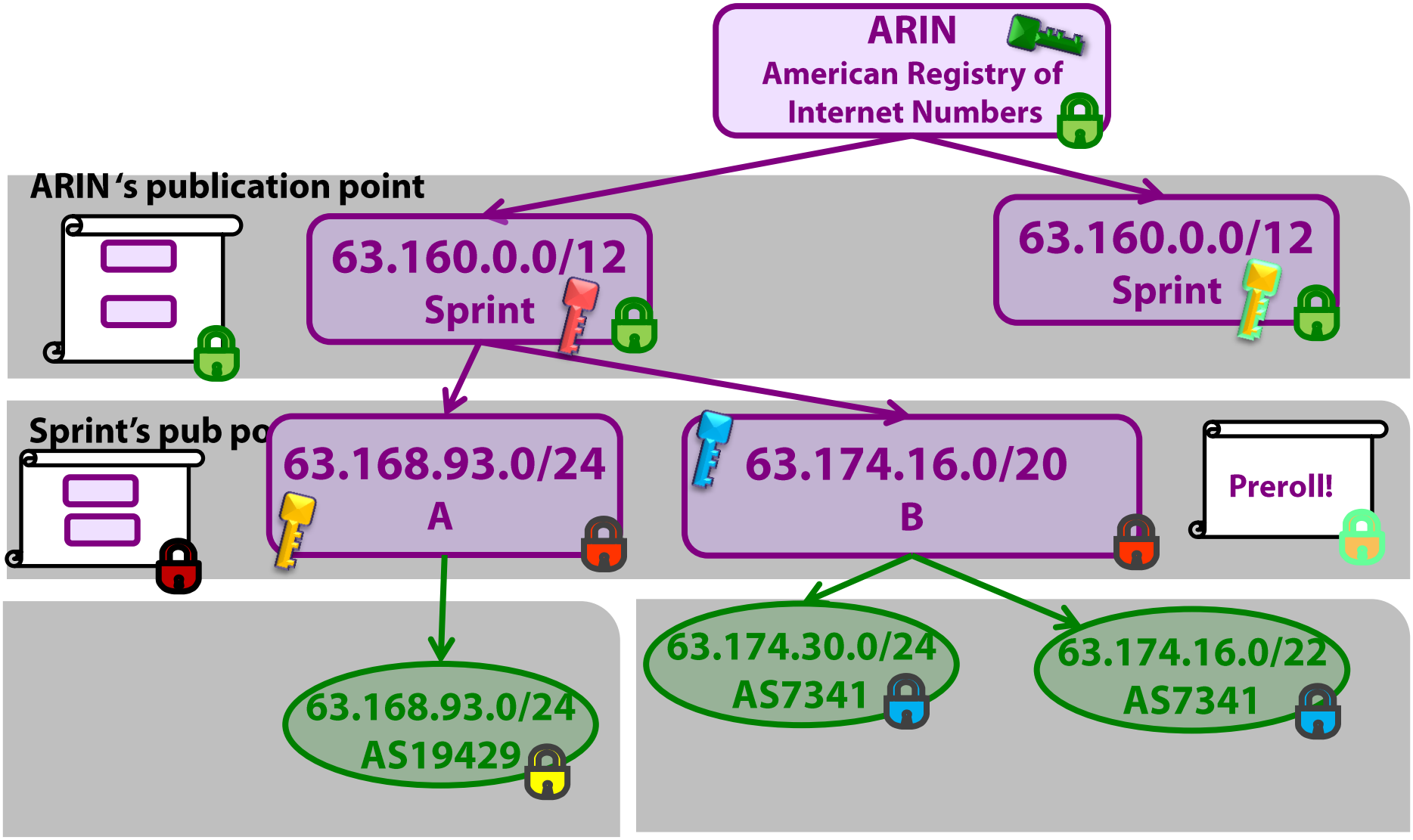
key rollover



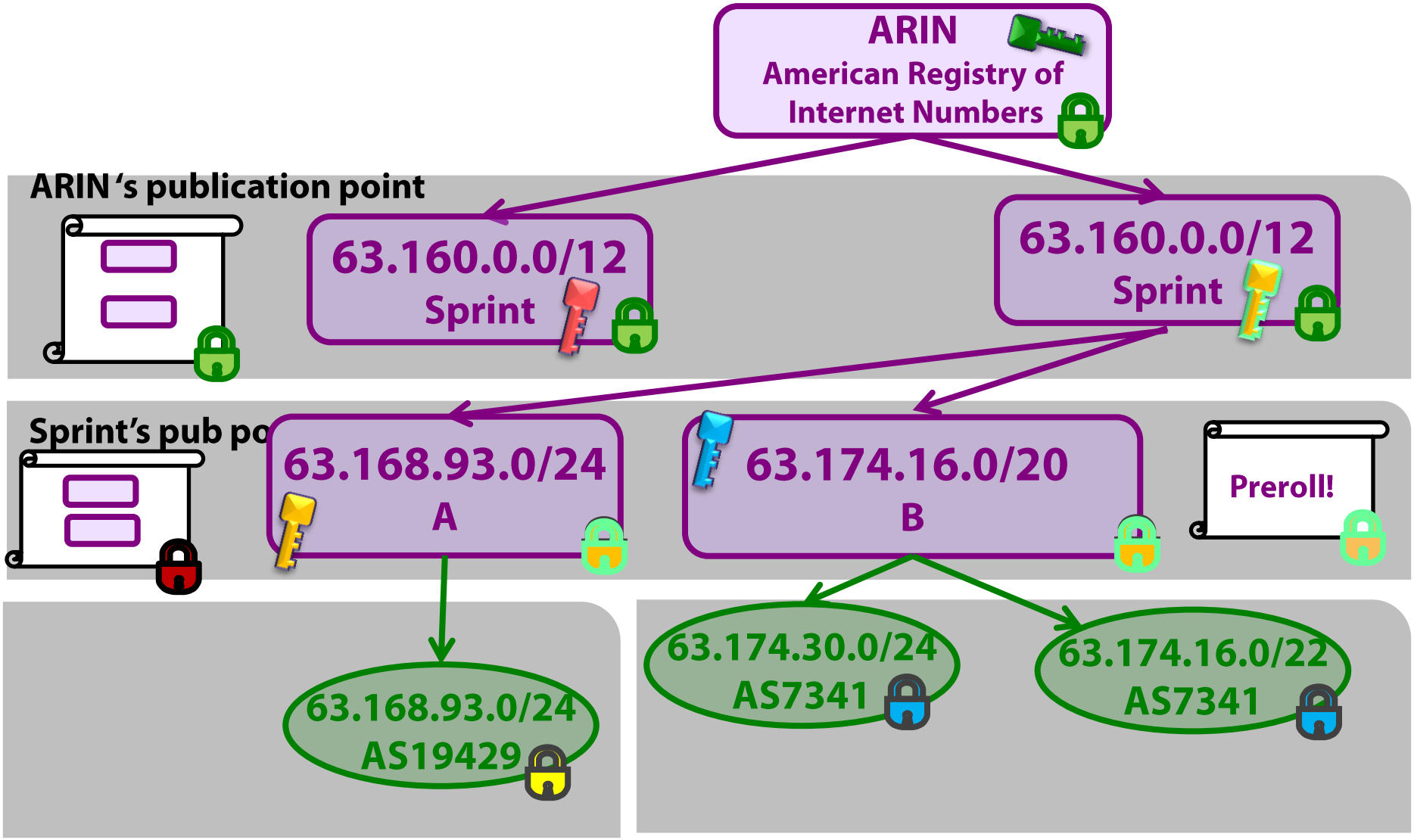
key rollover (step 0



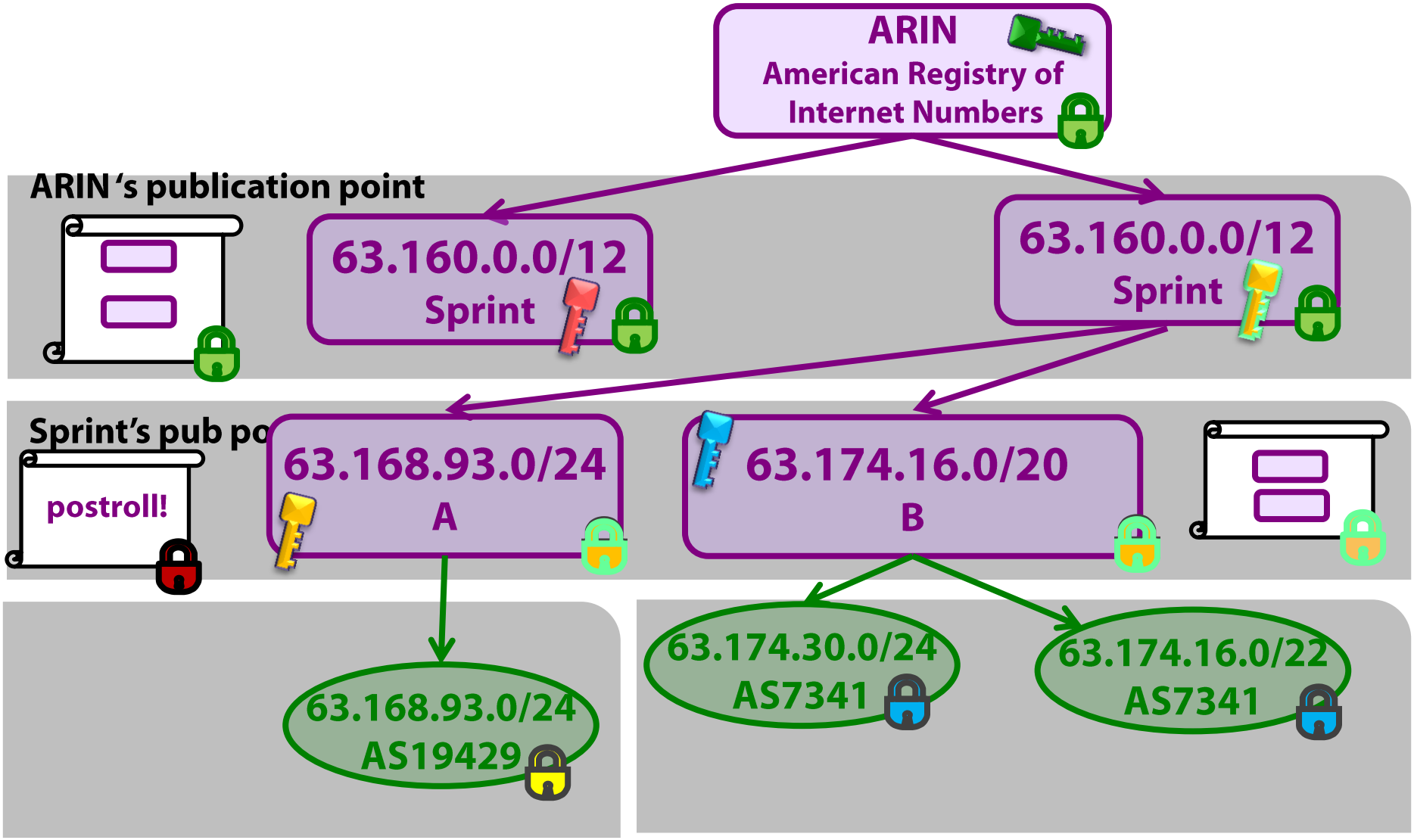
key rollover (step 1)



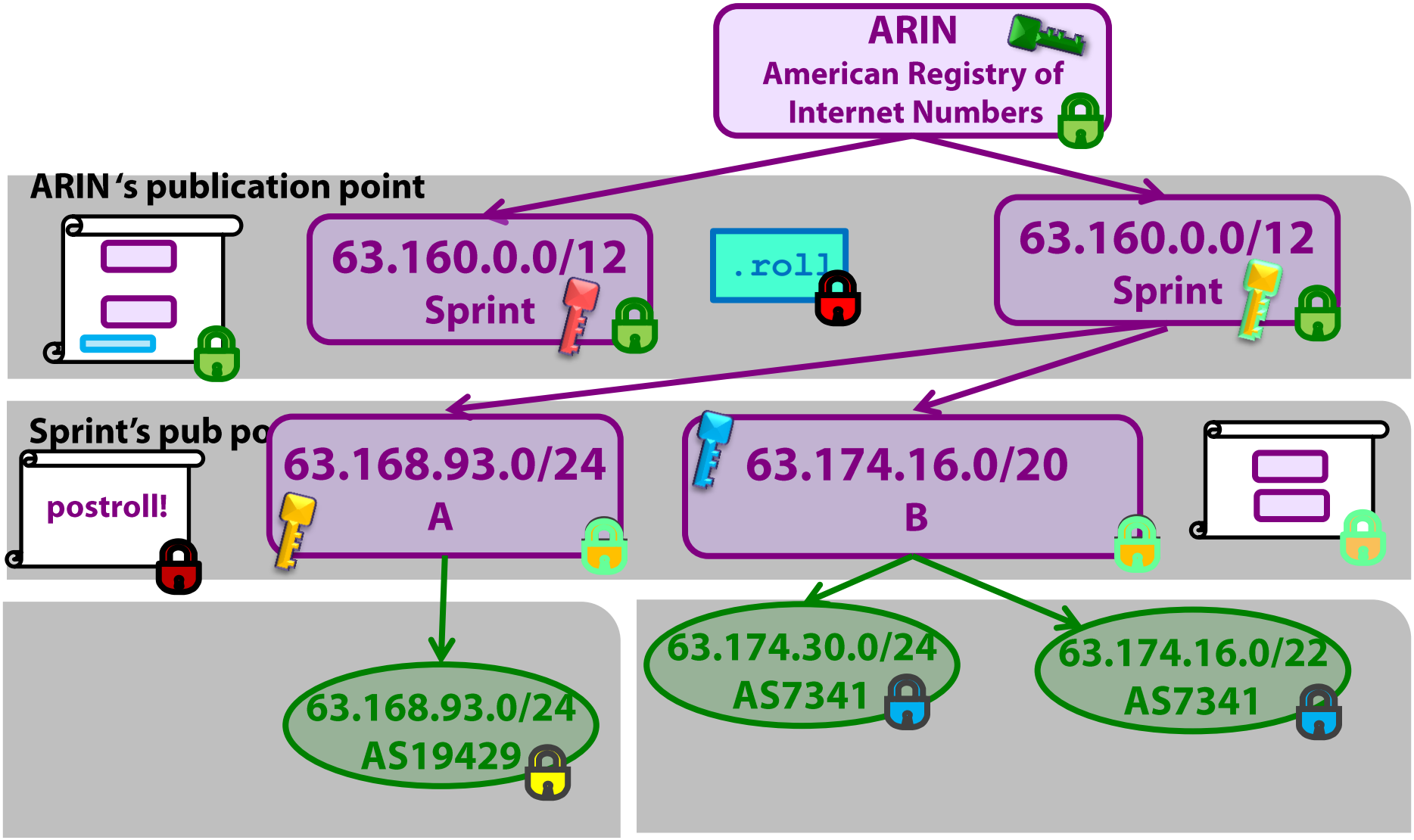
key rollover (step 2)



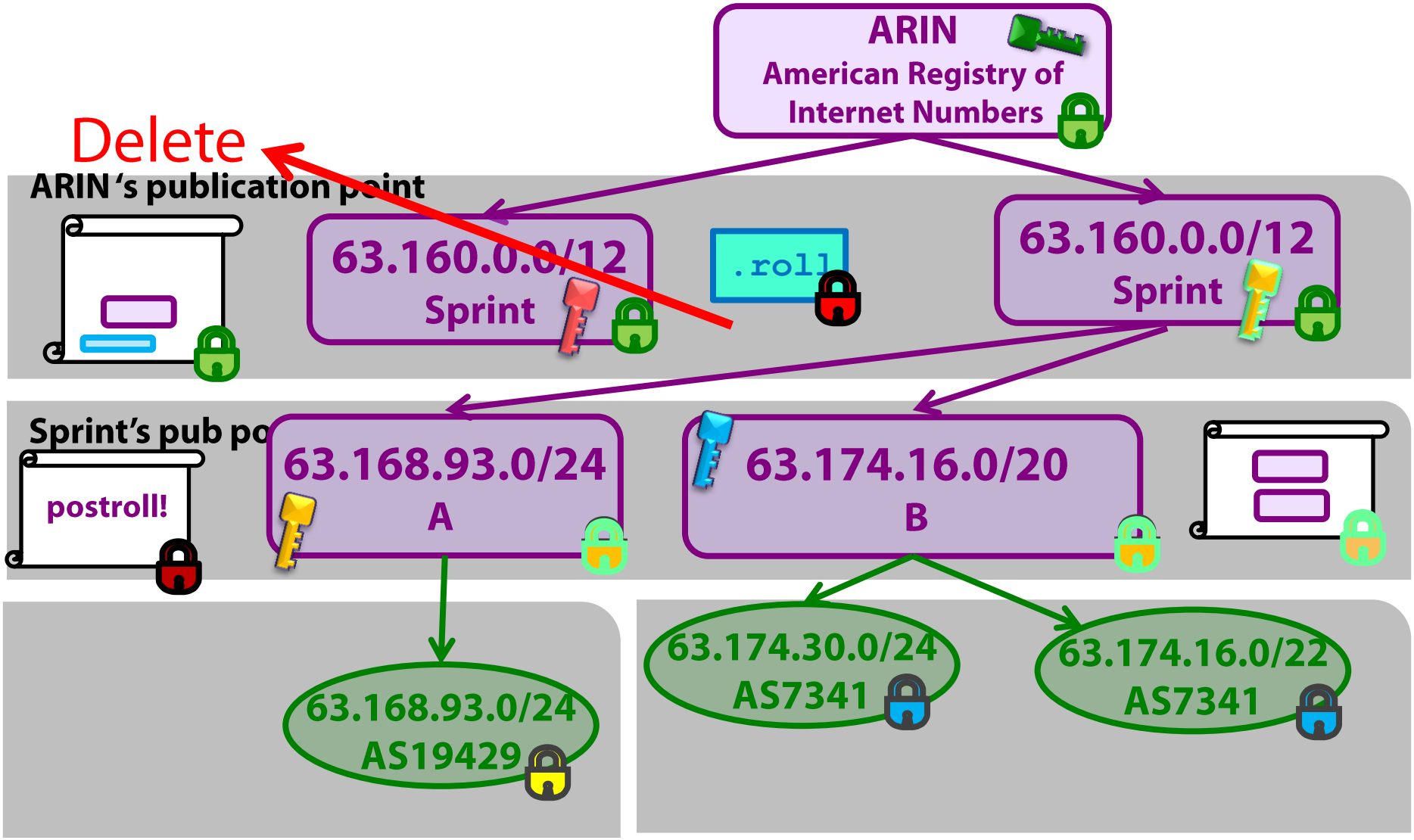
key rollover (step 2)



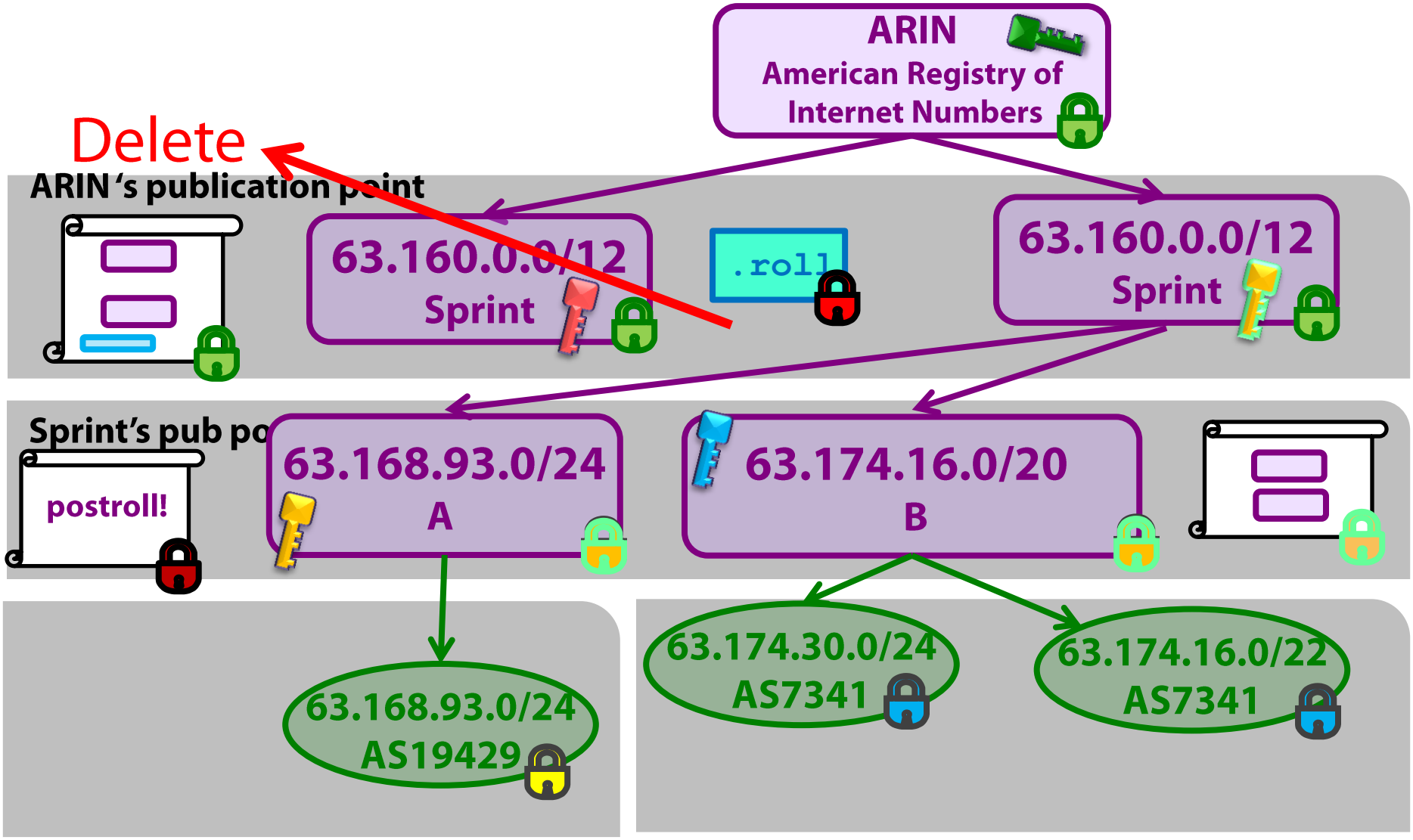
key rollover (step 3)



key rollover (step 3)

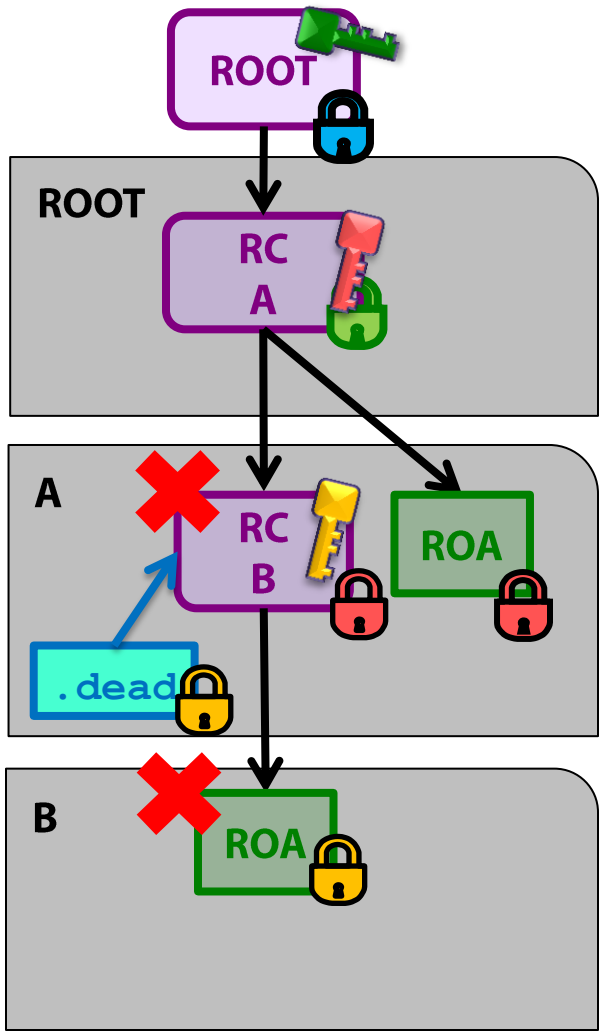


key rollover (step 3)



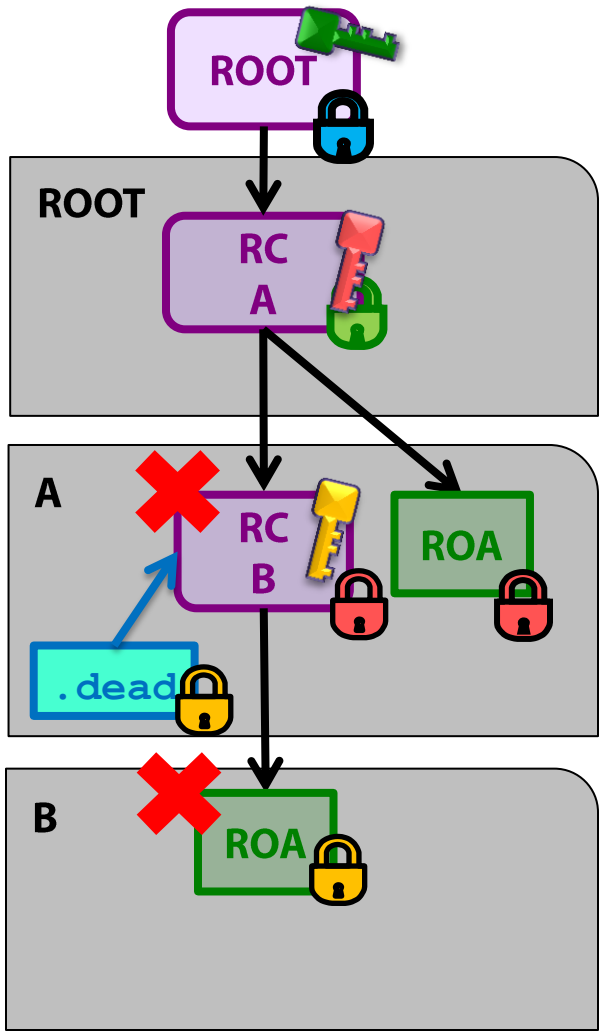
our proposal vs suspenders

our proposal [SIGCOMM'14]

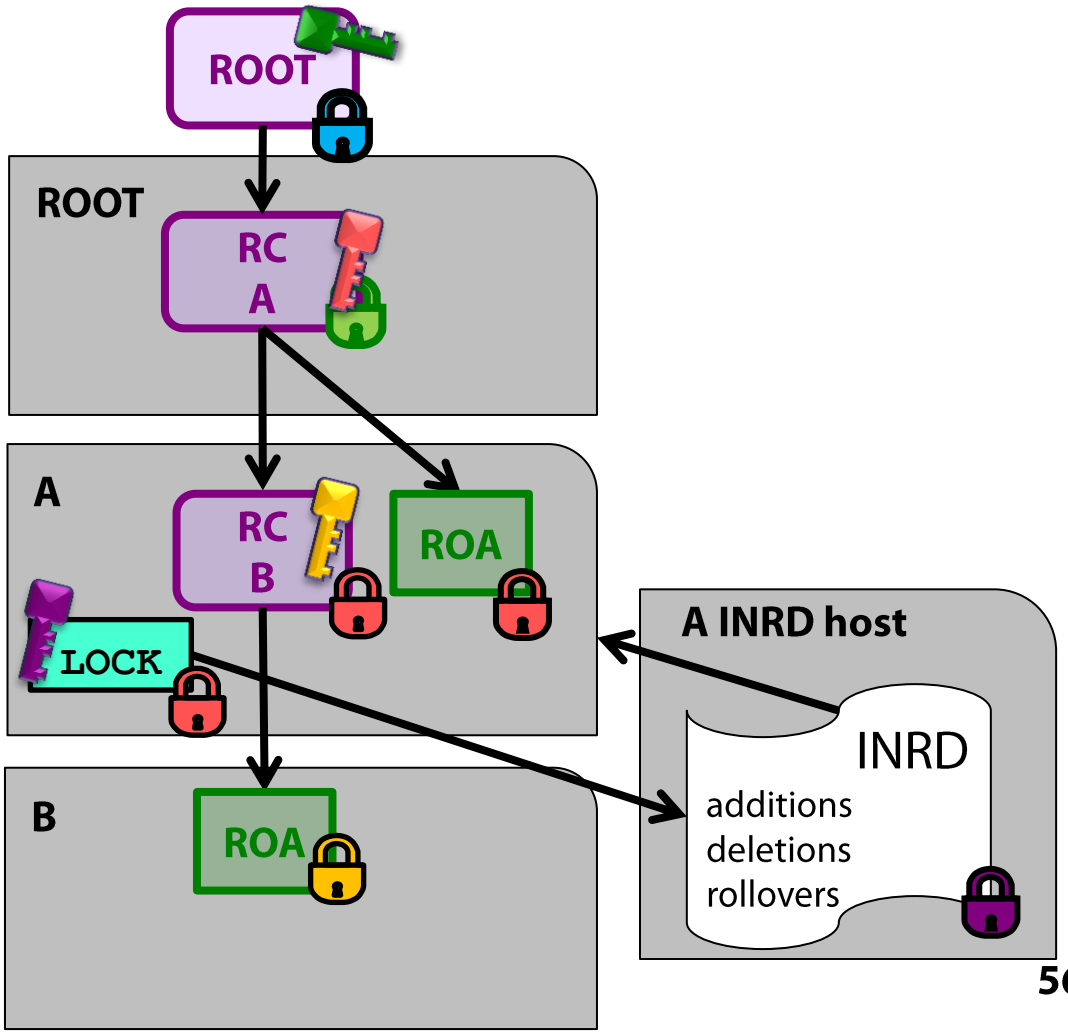


our proposal vs suspenders

our proposal [SIGCOMM'14]

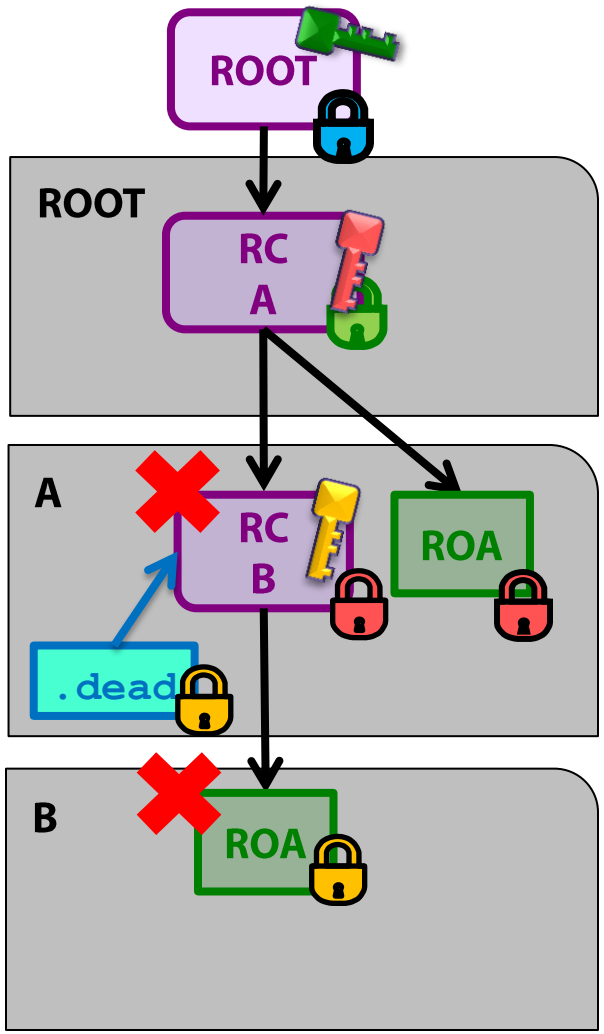


suspenders [draft-kent-sidr-suspenders-02]

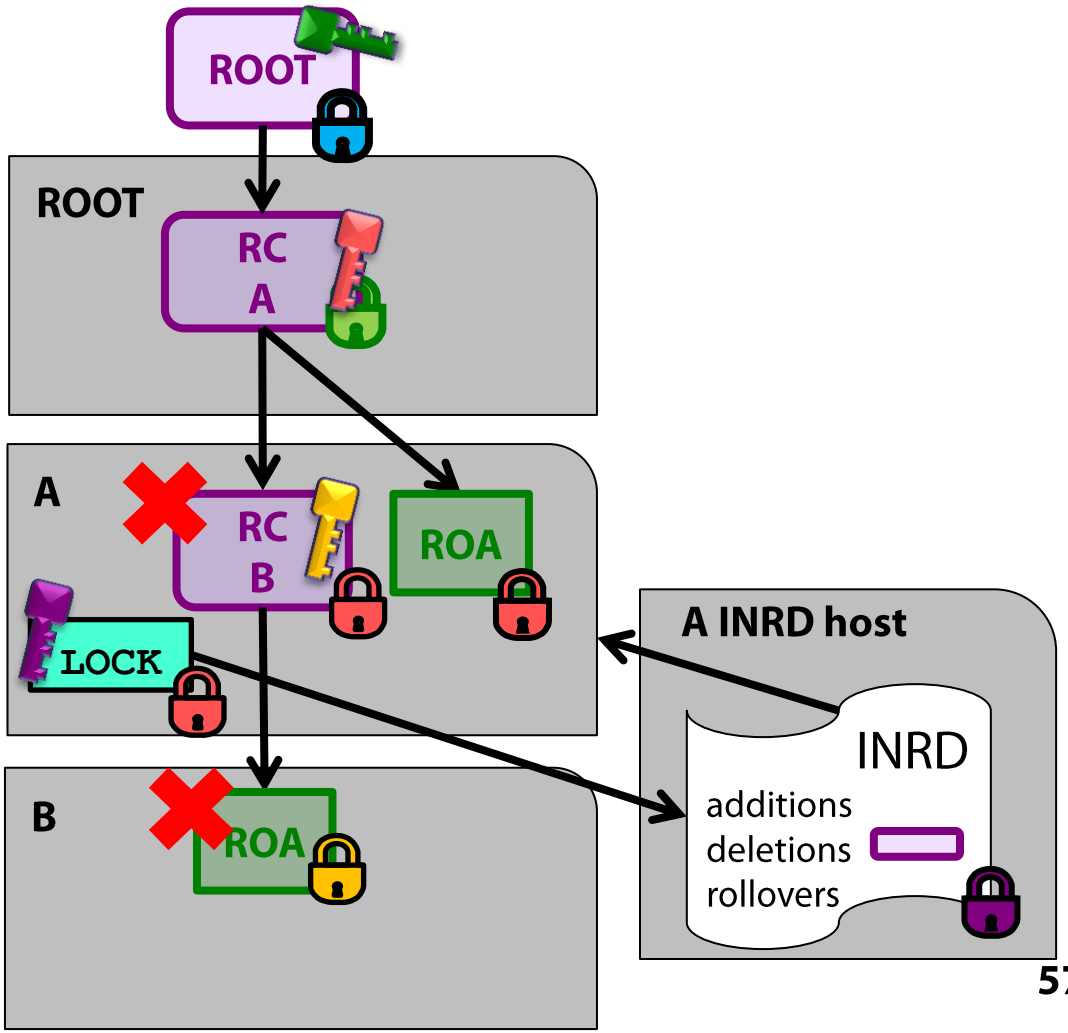


our proposal vs suspenders

our proposal [SIGCOMM'14]



suspenders [draft-kent-sidr-suspenders-02]



our proposal vs suspenders

		Our proposal	Suspenders
	Auditor:	Any Relying Party	
	Consent for whacking?	Yes: RCs	Yes: RCs & ROAs
	"Consent" for "ROA competition"?	No	Yes
	Consistency?	Yes	No
Requiren	Limited non-repudiation?	Yes	No?

our proposal vs suspenders

		Our proposal	Suspenders
	Auditor:	Any Relying Party	
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	"Consent" for "ROA competition"?	No	Yes
	Consistency?	Yes	No
	Limited non-repudiation?	Yes	No?
Design	New RPKI objects:	.dead .roll change logs	LOCK INRD
	Requires changes to manifests?	Yes	No

our proposal vs suspenders

		Our proposal	Suspenders
	Auditor:	Any Relying Party	
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	"Consent" for "ROA competition"?	No	Yes
	Consistency?	Yes	No
	Limited non-repudiation?	Yes	No?
Design	New RPKI objects:	.dead .roll change logs	LOCK INRD
	Requires changes to manifests?	Yes	No
	"Out of band" publication points?	Yes	No
	"Consenting" subjects need keys?	Yes	Yes
	Proofs of security goals:	Yes	No

Question for the room: What is the right set of requirements?

Who controls the root?

Is there a single root of trust? Unclear; IAB says yes.
Right now there are 25.

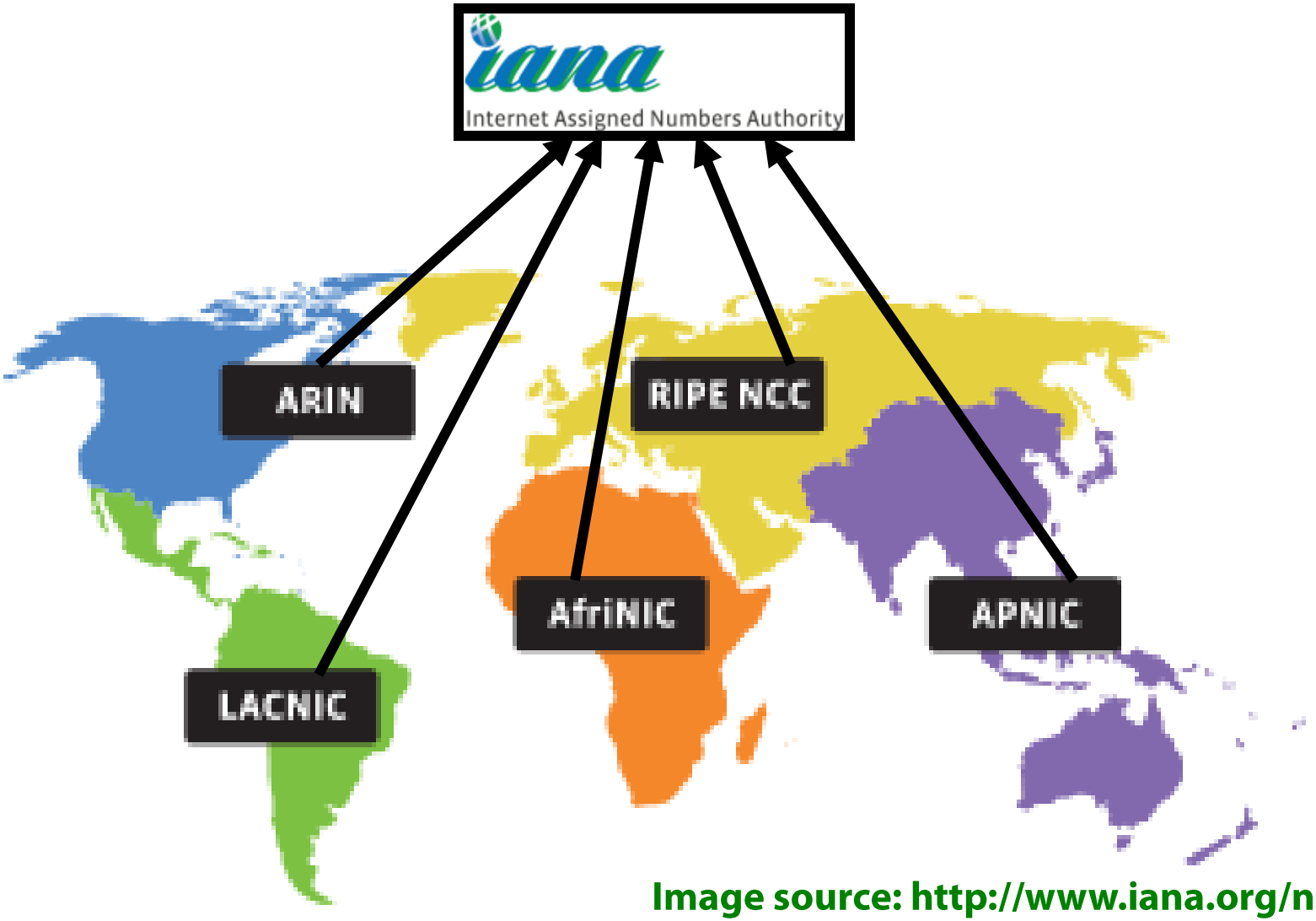
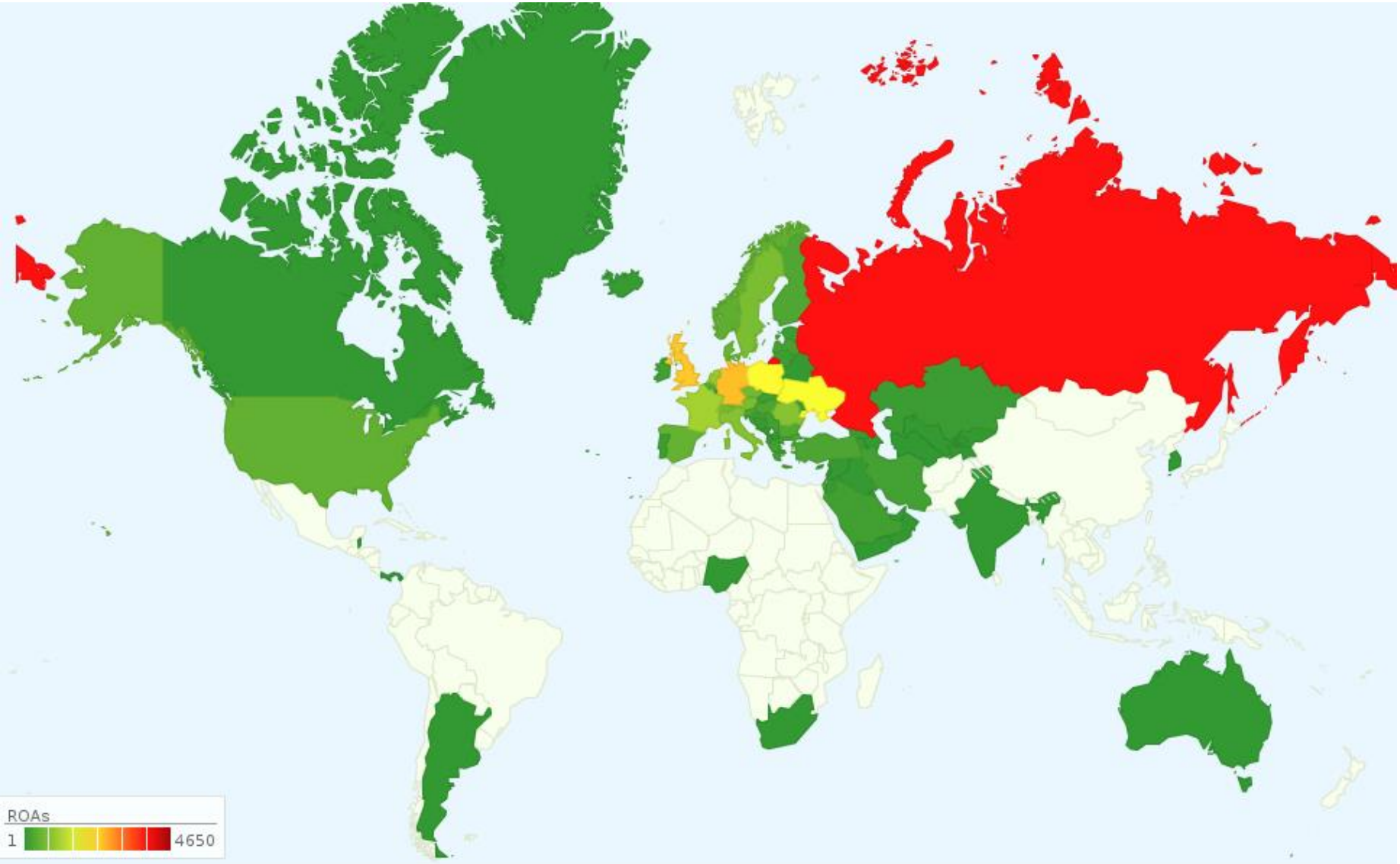
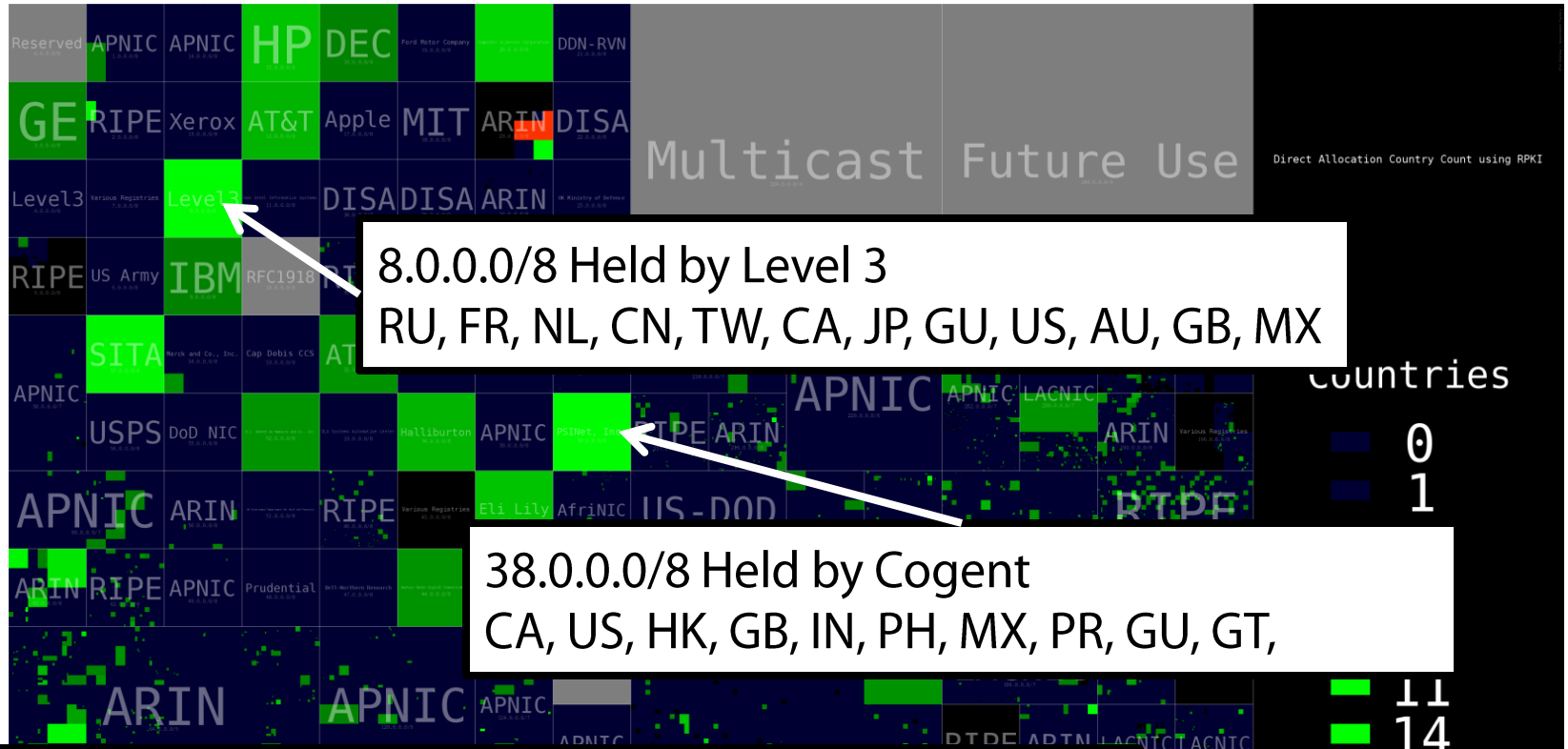


Image source: http://www.iana.org/numbers

Countries covered by RIPE



IPv4 address allocation does not reflect jurisdiction



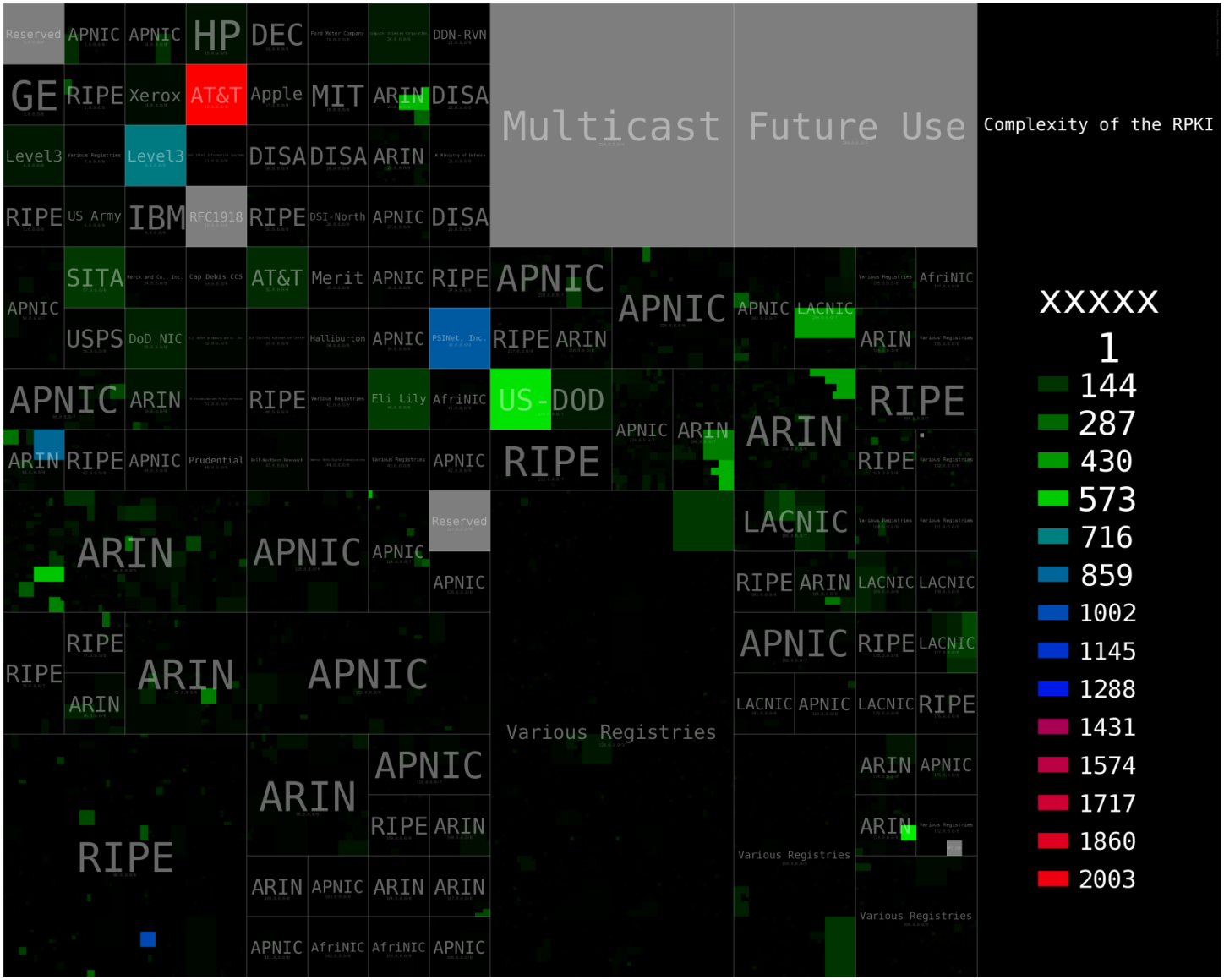
8.0.0.0/8 Held by Level 3
RU, FR, NL, CN, TW, CA, JP, GU, US, AU, GB, MX

38.0.0.0/8 Held by Cogent
CA, US, HK, GB, IN, PH, MX, PR, GU, GT,

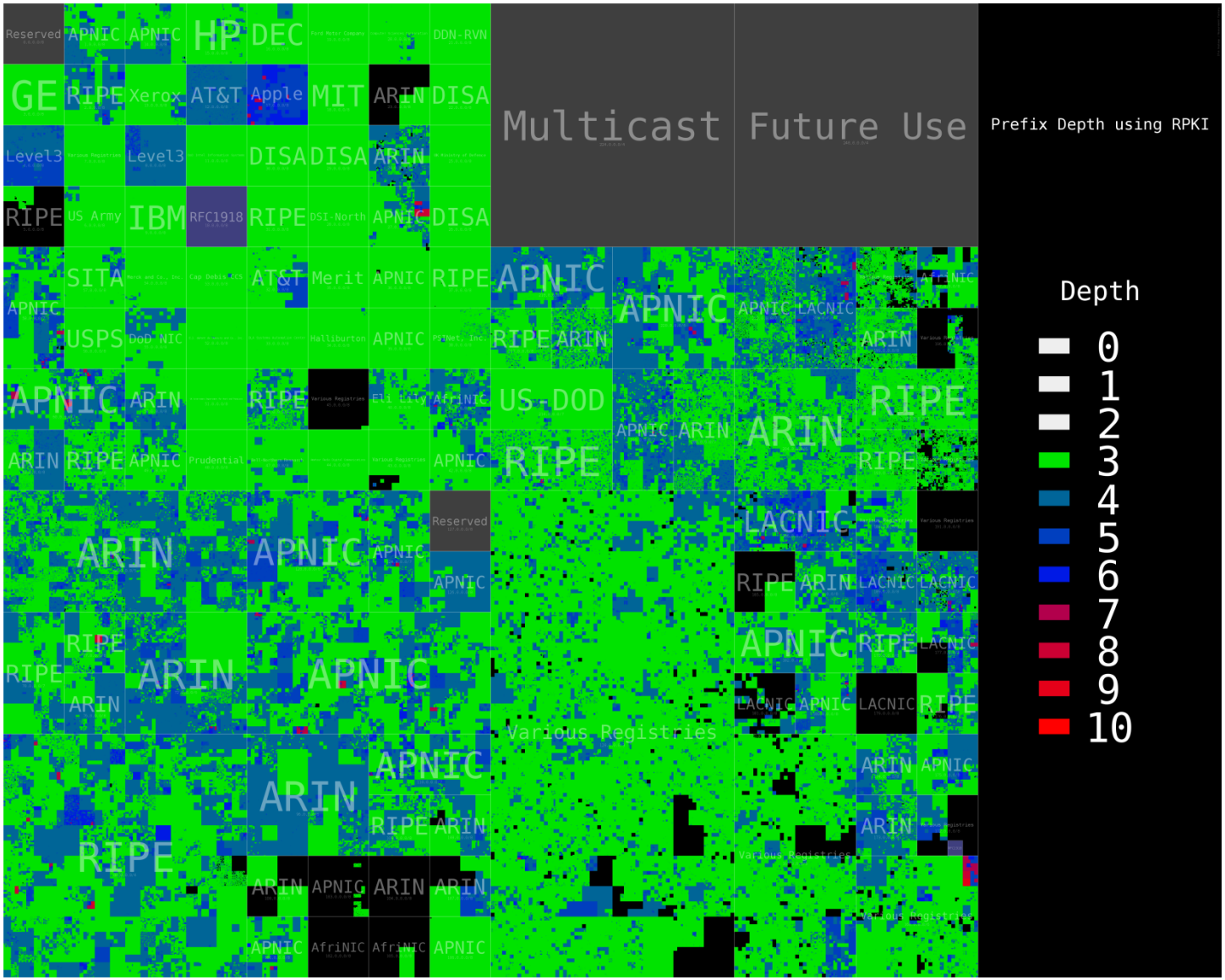
Data-driven model of the RPKI (today's RPKI is too small)

- ✧ Using RIR direct allocations, routeviews, BGP table dumps
- ✧ RIRs and their direct allocations get RCs, other (prefix,origin AS) pairs in the table dumps get a ROA
- ✧ ASes mapped to countries using RIR data

Number of ROAs issued by each direct allocation



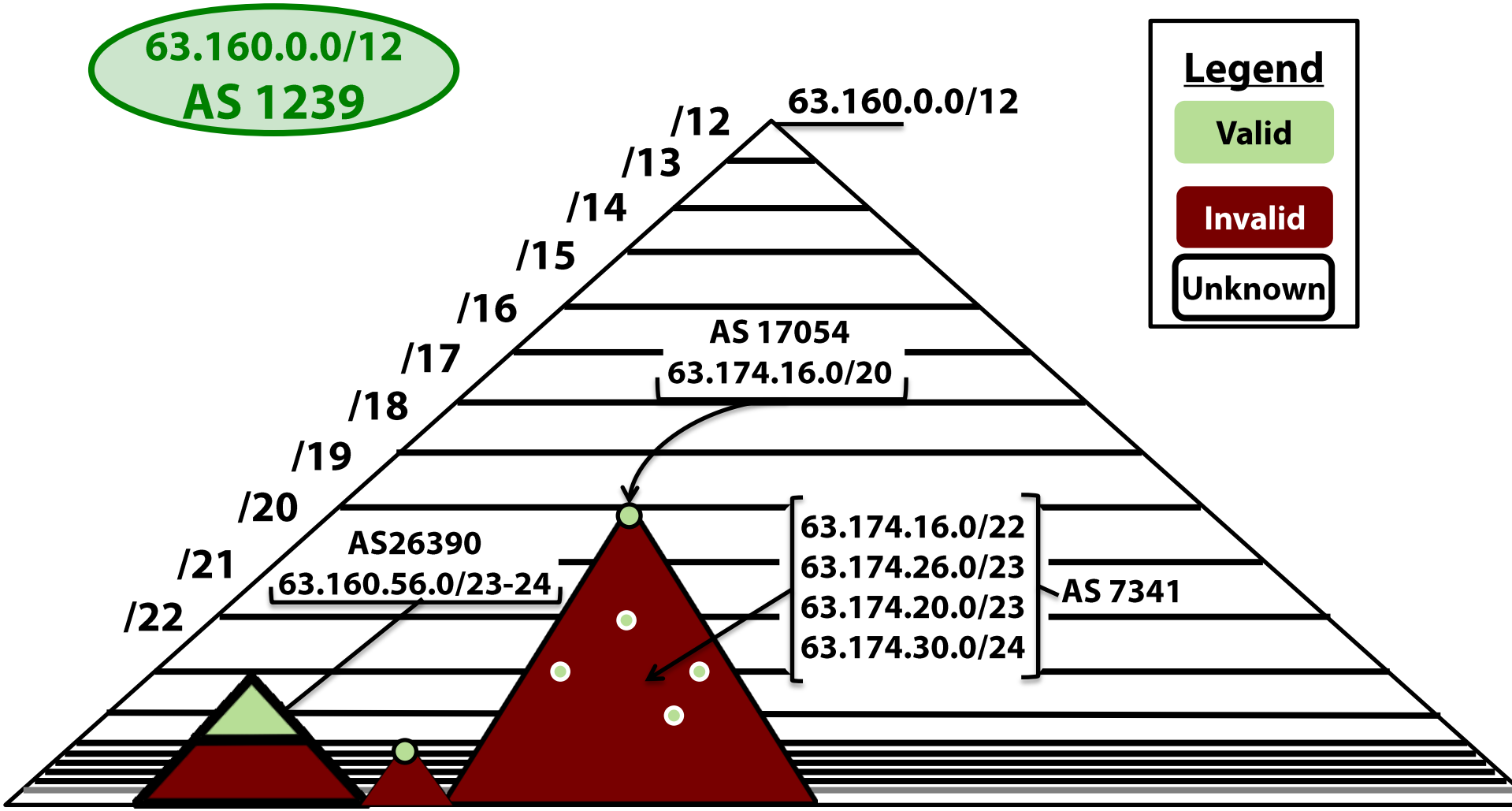
Depth of the RPKI



Depth	ROAs
3	118,028
4	108,043
5	10,863
6	293
7	9

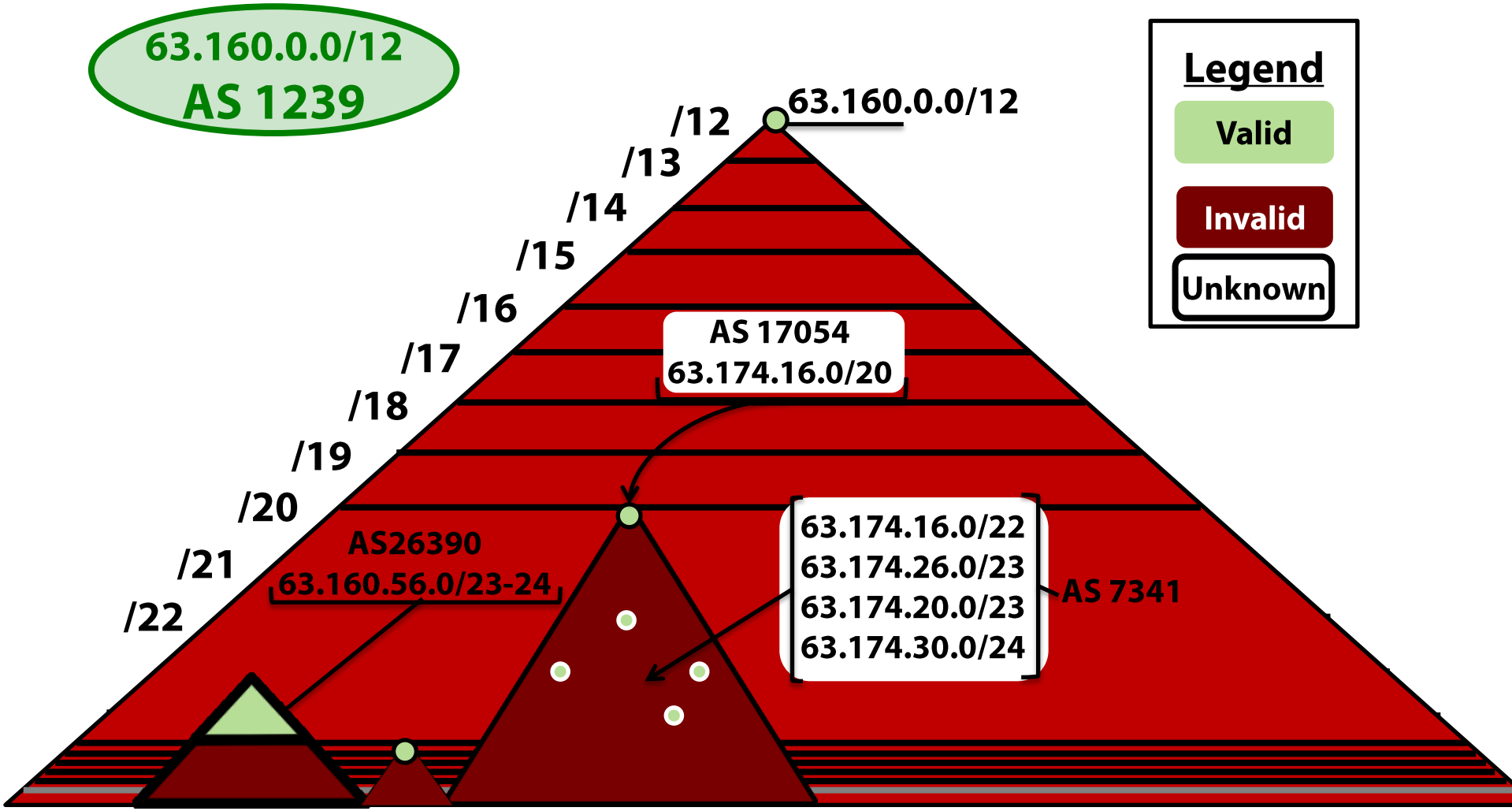
Route Validity Depends on More Than a Signature Chain

What if we add a ROA?



Adding a ROA Can Invalidate Routes!

What if we add a ROA?



Adding a ROA Can Invalidate Routes!

Why does this happen?

Otherwise, we can still subprefix hijack!

(more on this in a moment!)