The Transition to BGP Security
Is the Juice Worth the Squeeze?

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Work with Kyle Brogle (Stanford), Danny Cooper (BU), Ethan Heilman (BU), Robert Lychev (GATech/BU), Leonid Reyzin (BU), Michael Schapira (Hebrew U) from SIGCOMM’13 and HotNets’13
interdomain routing

BGP is used to learn routes between Autonomous Systems (ASes)

- nLayer, SCNet, 29997
  - 204.16.254.0/24

- SCNet, 29997
  - 204.16.254.0/24

- nLayer

- 29997
  - 204.16.254.0/24

- greenhost.nl

- NTT, nLayer, SCNet, 29997
  - 204.16.254.0/24

- Cyberbunker
  - 34109

- 0.ns.spamhaus.org
  - 204.16.254.40

- 204.16.254.0/24
the subprefix hijack of spamhaus from 03/2013

Source: https://greenhost.nl/2013/03/21/spam-not-spam-tracking-hijacked-spamhaus-ip/
the subprefix hijack of spamhaus from 03/2013

Source: https://greenhost.nl/2013/03/21/spam-not-spam-tracking-hijacked-spamhaus-ip/
& other routing incidents
**crypto to the rescue!**

BGP **Resource Public Key Infrastructure**  
(origin validation)  

- Deployment started in 2011.  
- Certifies IP prefix allocations.  
- Crypto done out-of-band  
- No change to BGP messages

BGPSEC  

- Builds on the RPKI  
- Now being standardized  
- Certifies announced routes  
- Crypto done online  
- Major change to BGP msgs

**Main challenge?**  
Incremental deployment & backward compatibility
our main goal: recommendations for protocol adoption

What are the security benefits of adopting these protocols?

What are the incentives for adopting them?

How do they alter trust relationships?
What are the security benefits of adopting these protocols?

- What does BGPSEC offer over the RPKI?
- Focus on the transition, when BGP and BGPSEC coexist.
- Experiments with deployment scenarios on empirical Internet topologies
- **Result:** We find that the RPKI is much more crucial than BGPSEC

How do they alter trust relationships?

- Analyze the RPKI in a threat model where certificate authorities are compromised.
part 1: security benefits of RPKI and BGPSEC

1. background: RPKI, BGPSEC
2. why BGP / BGPSEC coexistence is tricky
3. experimental evaluation of security for RPKI and BGPSEC
the RPKI defeats all subprefix & prefix hijacks
the “1-hop hijack” defeats the RPKI

(This exact situation is hypothetical, but this type of attack has been seen in the wild, See [Schlamp, Carle, Biersack 2013])
BGPSEC defeats the “1-hop hijack” (& all path-shortening attacks)
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The 1-hop hijack will be **BGPSEC invalid** because AS29997 never announced

34109: (29997, Prefix)
We suppose RPKI is fully deployed.

- prefix- and subprefix hijacks are eliminated.
- our threat model is therefore the 1-hop hijack

What happens when BGP and BGPSEC coexist?
BGPSEC in partial deployment

To communicate with legacy routers, BGPSEC-speaking routers must send and receive insecure routes.

Long secure route? Or short insecure route?

34109, 29997
204.16.254.40/24

Prefix

AS 29997
204.16.254.0/24

RPKI
how to prioritize security in partial deployment?

**BGPSEC Security 1st**

1. local preference (cost, business relationships)

2. prefer short routes ("performance")

3. tiebreak on interdomain criteria
how to prioritize security in partial deployment?

1. local preference (cost, business relationships)

   **BGPSEC Security 2**

2. prefer short routes ("performance")

3. tiebreak on interdomain criteria
how to prioritize security in partial deployment?

1. Local preference (cost, business relationships)

2. Prefer short routes ("performance")

3. Tiebreak on interdomain criteria

BGPSEC Security 3rd
how to prioritize security in partial deployment?

**BGPSEC Security 1st**
1. local preference (cost, business relationships)

**BGPSEC Security 2nd**
2. prefer short routes (“performance”)

**BGPSEC Security 3rd**
3. tiebreak on interdomain criteria

✧ Survey of 100 network operators shows that 10%, 20% and 41% would place security 1st, 2nd, and 3rd. [NANOG’12]

**Main question:** If everyone uses the same security model, what are the “security benefits” of deploying BGPSEC at a set of S ASes?
how to prioritize security in partial deployment?

BGPSEC Security 1st
1. Prefer customer paths over peer paths over provider paths

BGPSEC Security 2nd
2. prefer short routes ("performance")

BGPSEC Security 3rd
3. tiebreak on interdomain criteria

Survey of 100 network operators shows that 10%, 20% and 41% would place security 1st, 2nd, and 3rd. [NANOG’12]

Main question: If everyone uses the same security model, what are the “security benefits” of deploying BGPSEC at a set of S ASes?
A protocol downgrade attack. (Suppose security is 3rd)

To communicate with legacy routers, BGPSEC-speaking routers must send and receive insecure routes.
Let $S$ be the set of ASes deploying BGPSEC

The number of ASes choosing a legitimate route is

$$\text{Happy}[S, a, d] = 3$$

Our security metric averages this over all $a$ and $d$.

But, it’s hard to find the “right” $S$:

- Future deployment patterns are hard to predict
- Finding $S$ (of size $k$) maximizing security metric is NP-hard

Instead, we quantify security *irrespective of the scenario $S$!*
ScNet and nLayer are immune! They choose the legitimate route regardless of who is secure.

greenhost is doomed! It chooses the bogus route regardless of who is secure.

Only NTT can be protected by BGPSEC.

(For this example, Security is 3rd)
Bounding security provided by any BGPSEC deployment

- Lower bound with RPKI
- Security metric: Average fraction of ASes choosing legitimate routes
- The maximum improvement for any BGPSEC deployment is 1 - (fraction of doomed ASes).
- Sec 1st: 47%
- Sec 2nd: 36%
- Sec 3rd: 17%
- Lower bound with RPKI: 53%
securing 113 high degree ASes & their stubs

BGP → RPKI → BGPSEC

50% of AS graph is secure

Security metric: Average fraction of ASes choosing legitimate routes

Sec 1st: 24%
Sec 2nd: 8%
Sec 3rd: 4%

53% lower bound with RPKI
methodology (& more results in [SIGCOMM’13])

✧ **Graph:** A UCLA AS-level topology from 09-24-2012
  ✧ 39K ASes, 73.5K and 62K customer-provider and peer links
✧ **LocalPref model:** The Gao-Rexford (& Huston) model:
  ✧ Prefer customer path over peer path over provider paths.
✧ **Traffic patterns:** All ASes equal; non-stub attackers.

Robustness Tests:
✧ **Graph:** added 550K peering links from IXP data on 09-24-2012;
✧ **Traffic patterns:** focused on certain destinations (e.g. content providers) and attackers
✧ **Local pref:** Repeating all analysis for different LocalPref models
The RPKI is the most crucial step from a security perspective
✧ Limiting the attacker to 1-hop hijacks already weakens him significantly

There is no free lunch with BGPSEC
✧ If security is not 1\textsuperscript{st}, protocol downgrade attacks are a serious problem
Part 2: How does the RPKI alter trust relationships?

flip the threat model: what if the RPKI is compromised?
the RPKI defeats all subprefix & prefix hijacks

- **ROA** (Route Origin Authorization)
  - **AS 29997**
  - **204.16.254.0/24**

- **NTT**
  - **AS 29997**
  - **204.16.254.0/24**

- **nLayer**
  - **34109, 51787, 1198**
  - **34109, 51787, 1198**
  - **204.16.254.40/32**

- **SCNet**
  - **29997**
  - **204.16.254.0/24**

- **Cyberbunker**
  - **34109**
  - **204.16.254.40/32**

- **greenhost.nl**

- **Drop RPKI invalid routes!**

- **AS 29997**
  - **204.16.254.0/24**

- **RPKI**
RPKI challenges (discussed in [HotNets’13])

what you’d expect:
- **ROA** → **BGP msg**
  - valid → RPKI valid
  - invalid → RPKI invalid
  - Missing → RPKI unknown

creates issues for partial deployment, misconfigurations
RPKI challenges (discussed in [HotNets’13])

what really happens

ROA ➔ BGP msg

<table>
<thead>
<tr>
<th>valid</th>
<th>RPKI valid</th>
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creates issues for partial deployment, misconfigurations
**RPKI challenges (discussed in [HotNets’13])**

-**What really happens**
  - ROA → BGP msg
  - | Valid → RPKI valid |
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- Creates issues for partial deployment, misconfigurations

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<th>Routing policy:</th>
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**Diagram:**
- **The RPKI**
- **Route Validity**
- **Routing**
RPKI challenges (discussed in [HotNets’13])

what really happens

ROA → BGP msg

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drops Invalid subprefix hijacks possible

creates issues for partial deployment, misconfigurations

Route Validity

Routing policy:

<table>
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<th>routing hijack</th>
<th>RPKI problem</th>
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<tbody>
<tr>
<td>Drop Invalid</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>“Depref invalid”</td>
<td>subprefix hijacks possible</td>
<td>✓</td>
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RPKI challenges (discussed in [HotNets’13])

what really happens
ROA \rightarrow BGP msg

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creates a new technical means to seize an IP prefix

creates issues for partial deployment, misconfigurations

Route Validity

Routing policy:

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IP prefixes can be seized…

But, lots of collateral damage.
IP prefixes can be seized in a **targeted** manner...

Sprint’s repository

- **63.160.56.0/23-24**
  - AS26390

- **63.168.93.0/24**
  - ETB S.A. ESP.

- **63.168.93.0/24**
  - AS19429

- **63.160.0.0/12**
  - Sprint

- **63.174.16.0/20**
  - Continental Broadband

- **63.174.26.0/23**
  - AS7341

- **63.174.20.0/23**
  - AS7341

- **63.174.30.0/24**
  - AS7341

- **63.174.16.0/22**
  - AS7341

- **63.174.16.0/20**
  - AS7341

**ARIN**
American Registry of Internet Numbers
IP prefixes can be seized in a **targeted** manner...

- **63.160.0.0/12**
  - Sprint

- **63.174.16.0/20**
  - except 63.174.22.0/24
  - Continental Broadband

- **63.160.56.0/23-24**
  - AS26390

- **63.168.93.0/24**
  - ETB S.A. ESP.

- **63.168.93.0/24**
  - AS19429

- **63.174.26.0/23**
  - AS7341

- **63.174.20.0/23**
  - AS7341

- **63.174.30.0/24**
  - AS7341

- **63.174.16.0/22**
  - AS7341

- **63.168.93.0/24**
  - AS19429
... that can cross international borders.

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
✧ Plot results on a Hilbert Curve of IPv4 address space
... that can cross international borders.
RPKI is the most crucial step in terms of security
• BGPSEC provides marginal gains;
• hard to realize these gains due to conflicting priorities in routing policies

RPKI alters trust relationships
• creates a small number of powerful authorities; crosses international borders
• Important work needs to be done to make RPKI more robust, including:
  – Recommendations for routing policies
  – Increasing certificate transparency (monitoring, logging, pinning, notaries)
  – And various other things (circular dependencies, partial deployment, etc)
Thanks!

Is the Juice Worth the Squeeze? BGP Security in Partial Deployment
Robert Lychev, Sharon Goldberg, Michael Schapira.
SIGCOMM'13, Hong Kong, China. August 2013

On the Risk of Misbehaving RPKI Authorities
Danny Cooper, Ethan Heilman, Kyle Brogle, Leonid Reyzin, Sharon Goldberg