The Scourge of Excessive AS-SETs

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Disclaimer: AS-SETs vs AS_SETs

NOTE: This talk discusses the **IRR AS-SET** object type!

- A record in the IRR database that defines a group of ASNs used to simplify the management of routing policies by grouping multiple ASNs together.
- Each AS-SET has a maintainer, often the user of the ASNs and Prefixes

Not **BGP AS_SET** construct, which has slated for deprecation.

- See Deprecation of AS_SET and AS_CONFED_SET in BGP (BCP 172, RFC 6472).
- Aggregate AS_SETs appear in the AS_PATH of a BGP announcement as one or more ASNs surrounded by curly brackets.
- Ex: 300 {200,100}. This set indicates that the aggregate summarizes routes that have passed through AS200 and AS100.

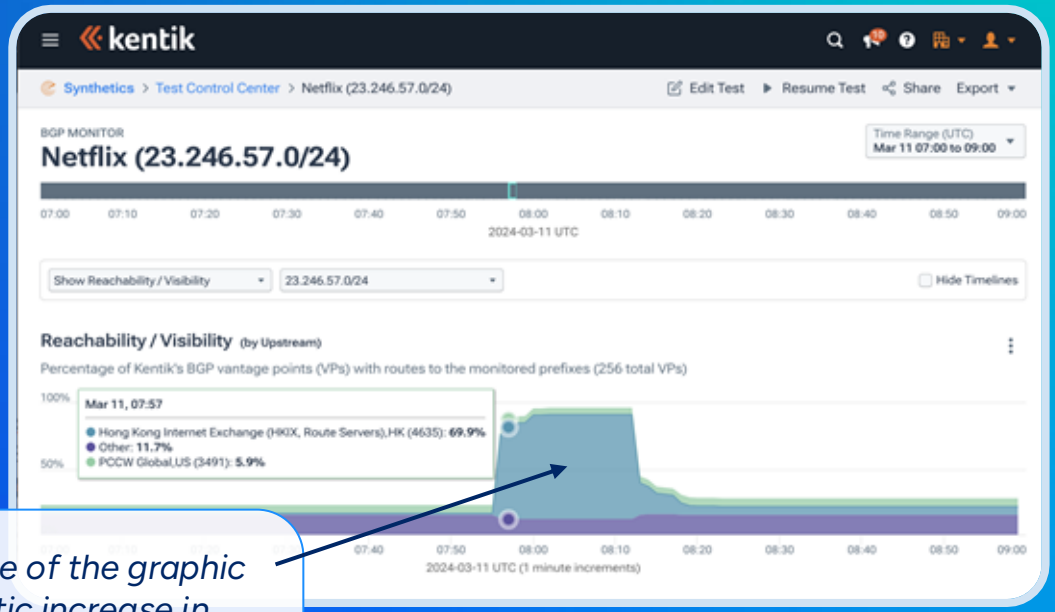
AS-SETs and BGP Leaks

On 07:56 UTC on March 11, 2024, Russian mobile operator MTS (AS8359) mistakenly propagated over 30,000 routes learned from the Hong Kong Internet Exchange (HKIX, AS4635) to its transit providers Lumen (AS3356) and Arelion (AS1299).

AS-SETs and BGP Leaks

Propagation of one Netflix's BGP routes announced at HKIX.

- Normally circulated only regionally.
- During the leak, the leaked version via AS8359 propagated globally.



The bulge in the middle of the graphic represents the dramatic increase in the number of our BGP sources who had this route in their table (with HKIX as the upstream).

AS-SETs and BGP Leaks

Hey, mistakes happen! 🤷‍♀️

Since this was an adjacency leak (aka path leak), RPKI ROV can't help.

At least we have AS-SETs to enable transit providers to programmatically build an appropriate allowlist to prevent the propagation of leaked routes, right? ***Right?***

What are AS-SETs?

- In the Internet Routing Registries (IRR), an AS-SET is a special database object type that represents a group of ASNs and other AS-SETs. It's primarily used for route filtering and policy control by ISPs and network operators.
- To build a prefix allowlist from an AS-SET, each member is recursively evaluated.
    - If the member is an ASN, the IRR is searched for route objects (route: for IPv4 and route6: for IPv6) which contain that ASN in the origin field.
    - Member AS-SETs are similarly recursively expanded into member ASNs, which are also expanded into their prefixes.
- The resulting prefix list can be loaded into the router's running configuration to be applied on the BGP session with the neighbor in question.

Note: IRR AS-SETs can be explored on the command line with Job Snijders' irrtree utility.

AS-SET Example

```
klootsJacBookPro:~ $ whois -h whois.ripe.net AS-MTU
as-set:         AS-MTU
descr:          ASes for MTS customers
members:        AS8359
members:        AS6870
members:        AS3327
members:        AS3203
members:        AS3205
members:        AS3711
members:        AS8359:AS-DSC-AS
members:        AS8410
members:        AS8441
members:        AS8706
members:        AS8848
members:        AS8920
members:        AS9130
members:        AS10099
members:        AS12335
members:        AS12456
members:        AS12500
members:        AS12668
members:        AS12686
members:        AS13016
members:        AS15454
members:        AS15455
members:        AS15640
members:        AS16012
members:        AS16094
members:        AS18608
```

```
members:        AS216140
members:        AS-29071-CLIENTS
members:        AS215182:AS-AVELACOM-BUSINESS
members:        AS-ADTEL
members:        AS-AITICON
members:        AS-ABAKANNET
members:        AS-AMTMGTS
members:        AS-AMSTEL
members:        AS-AMURTELECOM
members:        AS-ANNET
members:        AS-ARTCOMS
members:        AS-ARBUZ
members:        AS-AVANTEL
members:        AS-AVELACOM
members:        AS-AVANTRU
members:        AS-AVANTA
members:        AS-AGTEL-RUS
members:        AS-BELPAK
members:        AS-BETATELECOM
members:        AS-BAIKAL
```


Big challenges for AS-SETs

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No inherent quality, integrity, and authenticity controls over content.

✖

No limits to the number of AS members or AS-SETs that can be included.

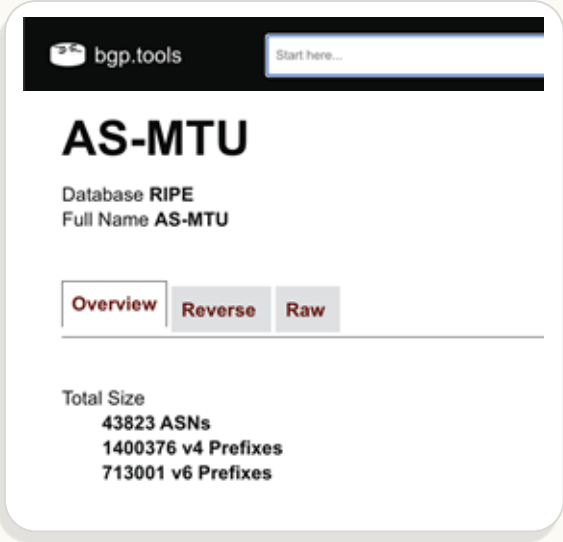
✖

No limits on the depth of the resulting recursion, which can lead to excessively large AS-SETs.

If an AS defines an AS-SET which includes the AS-SETs of some customers who contain AS-SETs, there can be a lack of awareness by the various parties of their implicit contribution to the resulting prefix list.

Excessively large AS-SETs

The leaker in the March 11 route leak uses an AS-SET called **`AS-MTU`**.



Web utility Bgp.tools lists the contents of AS-SETs.

- Expands AS-MTU to 43,823 ASNs!
- There are 83,617 ASNs in the global routing table.
- Any network applying AS-MTU as a filter for an interface with AS8359 is creating an allowlist containing these.

Some examples of prefixes allowed by AS-MTU	
6.2.0.0/17	US Department of Defense
8.36.240.0/20	Rural Telephone Service Company, Lenora, Kansas
12.10.219.0/24	American Express, Phoenix, Arizona
23.20.0.0/14	AWS EC2 for us-east-1
41.76.175.0/24	National Government of Kenya

Caution: AS-SETs vary by source IRR

Note the difference in output length for the three variations of the command when the source is set to APNIC, RIPE, and RADB.

(Note: Default source for bgpq4 is NTT's IRR mirror service.)

```
$ bgpq4 -S APNIC -Al eltel AS-VOXILITY-SET | wc -l
4773
$ bgpq4 -S RIPE -Al eltel AS-VOXILITY-SET | wc -l
50961
$ bgpq4 -S RADB -Al eltel AS-VOXILITY-SET | wc -l
86630
```

This is why it is important to indicate the authoritative source of the AS-SET, in PeeringDB for example.

Excessively large AS-SETs

A popular tool for building BGP filter lists based on IRR data is bgpq4: https://github.com/bgp/bgpq4

For **AS-MTU**, bgpq4 "-J" returns a Junos router configuration that is *almost 1.3 million lines long!*

```
$ bgpq4 -Jl eltel AS-MTU | wc -l
1294200
```

We can use the -A option to aggregate routes, reducing the lines of configuration to only a third of a million, but *it is still a lot*.

```
$ bgpq4 -Al eltel AS-MTU | wc -l
271171
```

The routes contained in this AS-SET represent 1.8 billion unique IPv4 addresses out of a total possible 3 billion addresses currently in the IPv4 routing table.

Excessively large AS-SETs

`AS-MTU` is not alone, nor anywhere near the worst!

So, what are the internet's largest (and most absurd) AS-SETs? Ben Cartwright-Cox, creator of Bgp.tools, ran the numbers.

- The biggest AS-SETs contain more ASNs than are in the global routing table (~90k).
- 2,192 AS-SETs expand to over 1,000 ASNs!

RIR	AS-SET	ASNes
RIPE	AS39533:AS-PEERS	102479
RIPE	AS-CLARANETDE-PEERINGS	102335
RADB	AS-ST1-IXPS	102332
RIPE	AS-MERKEL-PEERS	102313
RIPE	as-cloud-ix-pro	102305
RIPE	AS3326:AS-PEERS-DEE	102301
RIPE	AS-DECIX-V6	102300
RIPE	AS12732:AS-UPSTREAMS	102299
RIPE	AS-NFON-DECIX-PEERS-v4	102298
RIPE	AS-NFON-DECIX-PEERS-v6	102298

Unraveling nested AS-SETs

The observant reader might notice that these ASN counts exceed the number of ASNs in the global routing table (~90k) and might ask where the unrouted ASNs are coming from?

Well, they come from the myriad of downstream nested AS-SETs.

To investigate this phenomenon, Ben Cartwright-Cox wrote a script to traverse the nesting from an excessive AS-SET to one of its component unrouted ASNs, and the journey is wild.

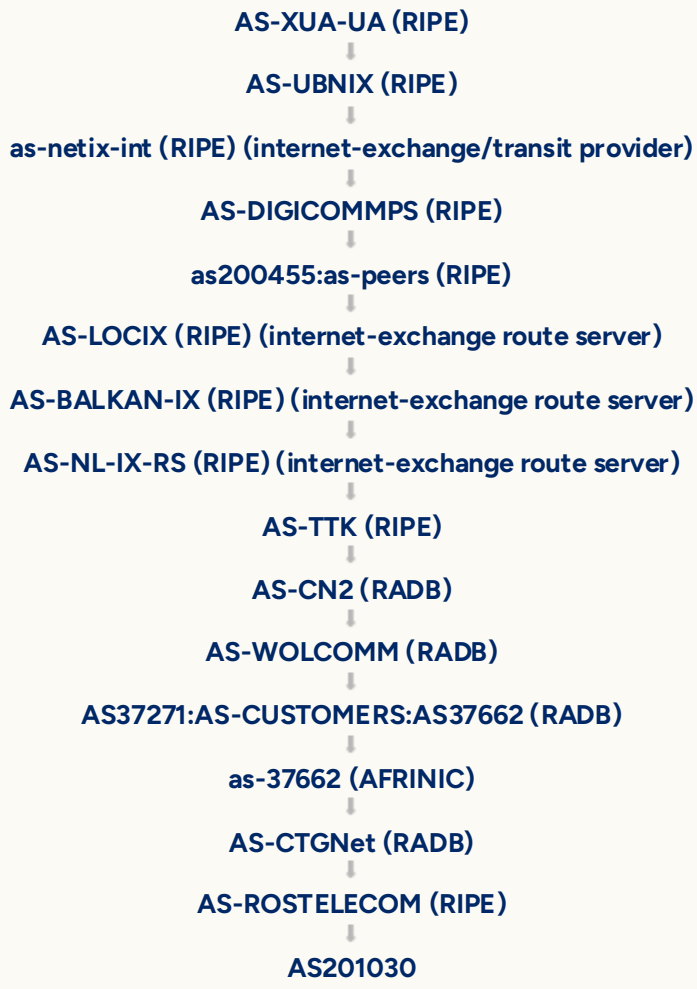
RIR	AS-SET	ASNes
RIPE	AS39533:AS-PEERS	102479
RIPE	AS-CLARANETDE-PEERINGS	102335
RADB	AS-ST1-IXPS	102332
RIPE	AS-MERKEL-PEERS	102313
RIPE	as-cloud-ix-pro	102305
RIPE	AS3326:AS-PEERS-DEE	102301
RIPE	AS-DECIX-V6	102300
RIPE	AS12732:AS-UPSTREAMS	102299
RIPE	AS-NFON-DECIX-PEERS-v4	102298
RIPE	AS-NFON-DECIX-PEERS-v6	102298

Unraveling nested AS-SETs

For example, AS-SET AS-XUA-UA from RIPE expands to almost 90,000 ASNs, including many unrouted ones.

How did an unrouted ASN wind up here?

This circuitous sequence of AS-SETs begins in **Ukraine** and includes, among other countries, **Bulgaria** (Balkan-IX), the **Netherlands** (NL-IX), **Russia** (TTK), **China** (CN2), **South Africa** (WOLCOMM), **China again** (CTGNet), and **Russia again** (Rostelecom), before landing on AS201030, the unrouted AS of "Public corporation for organisation of air traffic in the Russian Federation." Phew!



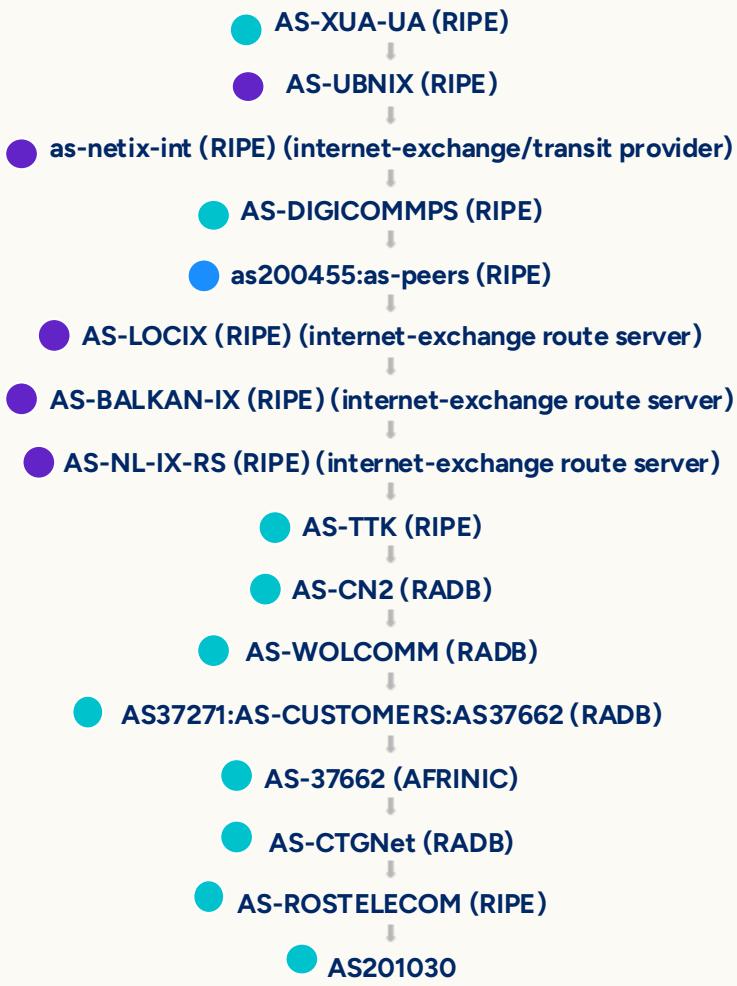
Unraveling nested AS-SETs

How did this list come to be?

There are (unofficially) different types of AS-SETs:

- Customers
- Peers
- IXP members

- The semantics of these are not really defined.
- The sequence on the right contains all three types.
- This mixing of types explodes the size of an AS-SET.
- The recursion explodes the size of an AS-SET



Why is this a problem?

- The March 2024 leak by AS8359 could have been exacerbated by its excessive AS-SET. It certainly didn't help.
- Our only hope to reduce harm from BGP mishaps is automation.
  - IRR data enables automated generation of allowlists (BGP session filters).
- Excessively large AS-SETs defeats the purpose of an allowlist.
- Excessively large AS-SETs also breaks automation!
  - Requires large amount of data to be repeatedly transferred and stored.
  - Generates extremely large (and unusable) router configurations.
- Providers have had to create workarounds to deal with this IRR pollution.

What's the solution?

1

Owners of AS-SET objects need to review any AS-SETs they define and ensure that they contain the minimum amount of ASes and AS-SETs to facilitate the creation of effective allowlists.

2

Ideally, AS-SET recursion is avoided where possible or at least kept to a minimum.

The downside of this "solution" is that it requires full and cognizant cooperation of all AS-SET holders, which is unrealistic in the global internet routing system.

To avoid inadvertent naming collisions, ISPs should follow the hierarchical naming practice when creating new AS-SETs.

What's the long(er) term solution?

1. Ultimately, the issue of BGP route leaks needs to be addressed through something better than unwieldy self-asserted allowlists.
2. Instead, the industry should use a combination of:
    - In-band BGP signaling, such as described in RFC 9234,
    - RPKI-based signaling using ASPA verification (work-in-progress),
    - Perhaps future RPKI extensions such as Signed Prefix Lists (work-in-progress).
3. IRR-based AS-SETs simply lack a degree of precision and contextual awareness to mitigate route leaks at scale.
4. Better to use a combination of in-band and out-of-band signals to ascertain whether a given BGP route announcement is a leak or not.

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Thank you!

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Special thanks to Ben Cartwright-Cox of bgp.tools for his AS-SET analysis.

Also, a big thanks to Tony Tauber (Comcast), Aaron Weintraub (Cogent), and Anees Shaikh (Google), Lasse Jarskov (Telia Company) for their feedback and suggestions.