Estimating the Used IPv4 Address Space with Secure Multi-party Capture-Recapture

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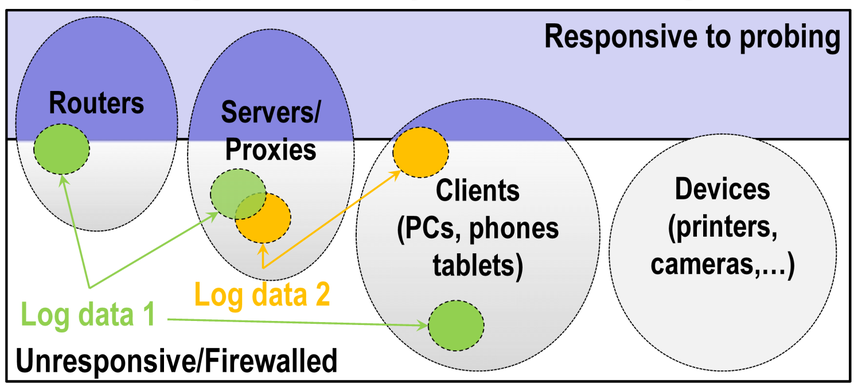
MOTIVATION

- How much "IPv4 reserves"?
  - Predict IPv6 deployment time frame
  - Predict potentially emerging IPv4 address market
- Measure progressive exhaustion of IPv4 space after it is allocated completely

CHALLENGES

- Can probe all IPv4s, but many **don't** reply [1]
- No sharing of **unanonymised** IPv4 logs



APPROACH

- Combine probing ("ping") with several traffic/server logs (multiple IPv4 sources)
- Estimate **unseen** IPv4 addresses with Capture-Recapture (CR) based on
  - Size of sources (assume **not** private)
  - Size of overlap of all source combinations
- Compute overlap without revealing IPv4s (secure set intersection size)

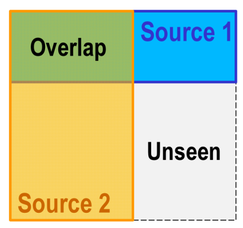
CAPTURE-RECAPTURE

- Predict total IPv4s N from multiple incomplete sources S_i

Two-source Lincoln-Petersen [2]

- Two independent sources
- Same sample probability for all IPv4s (no heterogeneity)

$$\widehat{N} = \frac{|S_1||S_2|}{|S_1 \cap S_2|}$$



Log-linear models [3]

- Multiple dependent sources
- Models source dependence due to heterogeneity

Source 1	Source 2	Source 3	Count
0	0	1	Z_{001}
0	1	1	Z_{011}
…	…	…	…
1	1	1	Z_{111}

Example: three sources counts

Step 1: Fit log-linear model based on counts

$$\log\left(E\left(Z_{ijk}\right)\right) = u + u_1 I(1,0,0) + u_2 I(0,1,0) + u_3 I(0,0,1) + u_{12} I(1,1,0) + u_{13} I(1,0,1) + u_{23} I(0,1,1) + u_{123} I(1,1,1)$$

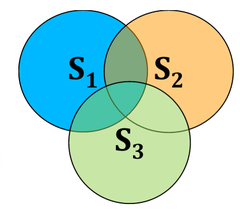
Step 2: Project model to estimate unseen/total

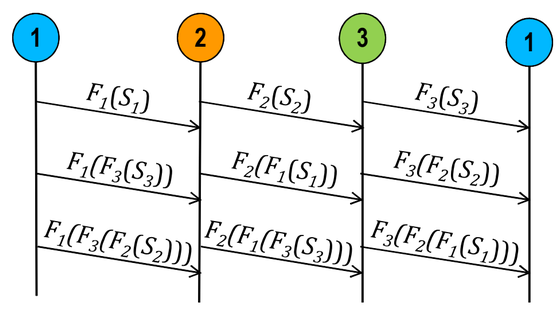
$$\widehat{N} = \sum Z_{ijk} + \hat{Z}_{000}$$

- Stratification by allocation RIR, country, age, prefix size, industry
- CR estimates IPv4s unseen by chance (focus on **routed** space)

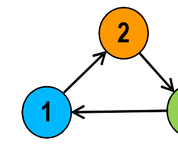
SECURE SET INTERSECTION SIZE

- Securely compute intersection sizes using permutation and **commutative encryption [4]** function F_i (with private key k_i)
  - Pohlig-Hellman encryption: $C = \left(P^{k_1}\right)^{k_2} \bmod n = \left(P^{k_2}\right)^{k_1} \bmod n$
- Compute IPv4s only in S_i, e.g. $Z_{001} = |S_3| - Z_{011} - Z_{101} - Z_{111}$
- Securely compute counts Z_{ijk} for all intersections
  - Collaborators permute and encrypt each (encrypted) data source starting with their own



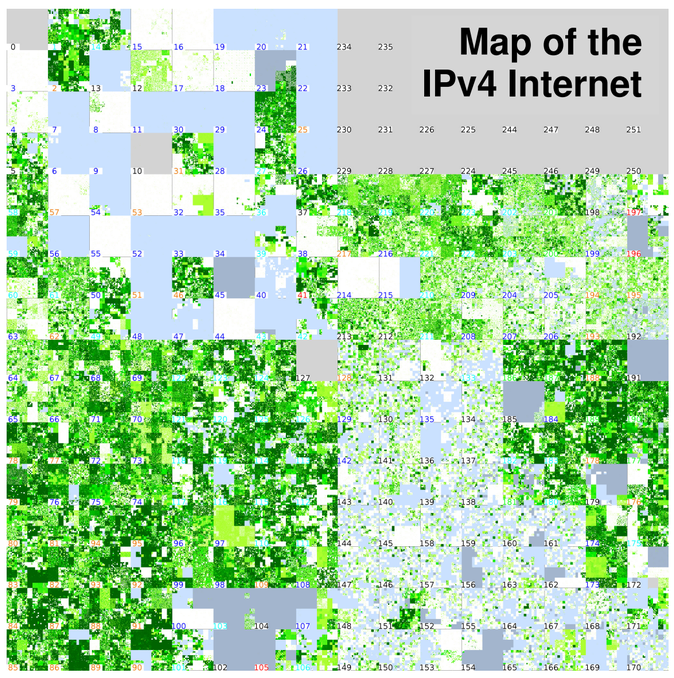


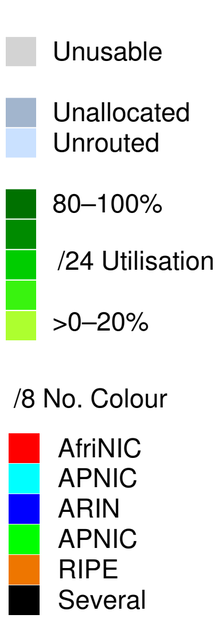
Ring topology

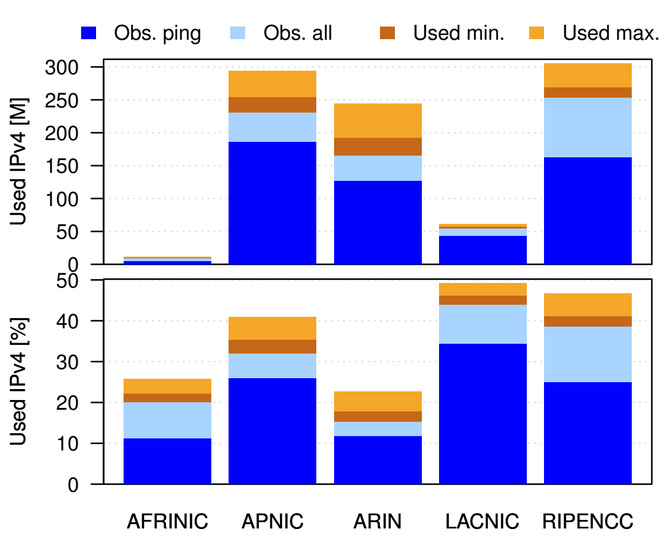


- Collaborators distribute *n*-party-encrypted datasets and intersect, e.g. $|S_1 \cap S_2| = |F_3(F_2(F_1(S_1))) \cap F_1(F_2(F_3(S_2)))|$
- Increase scalability with deterministic sampling of IPv4s

PRELIMINARY RESULTS







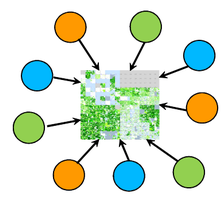
IPv4 address utilisation per Regional Internet Registry (RIR)

- **524** million addresses responsive (ICMP echo, TCP SYN port 80)
- **714** million alive addresses (all sources)
- **790–920** million used addresses estimated with CR (Lincoln-Petersen)
- **30–35%** of routed IPv4 space used

Data from Jan 2011 to Mar 2013. Collaborators: **APNIC**, **Caltech**, **Valve Corp.**

GETTING INVOLVED

- We seek more collaborators to share IPv4 address data
- Contribute unanonymised or anonymised data
- Contact: Sebastian Zander **szander@swin.edu.au**



http://www.caia.swin.edu.au/sting

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